INDOOR AIR QUALITY:
DEVELOPING GOVERNANCE POLICIES AND REGULATIONS

A dissertation submitted to Johns Hopkins University in conformity with the requirements for the degree of Doctor of Public Health

by

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Abstract

This paper is part of a project conducted by Abu Dhabi Public Health Center (ADPHC). The project is part of the Health Sector Strategy, Wellness and Prevention theme, identified as 'Community Risks and Environmental Health,' within the Abu Dhabi strategic master plan goal.

This initiative is also linked to the Abu Dhabi Emirate Environmental Vision 2030 and the Abu Dhabi plan goal 18: 'Sustainable Environment and Optimal Exploitation of Resources to preserve the Natural Heritage,' coordinated by the Environment Agency—Abu Dhabi (EAD), where EAD is leading on several initiatives aimed at improving air quality, marine water quality, community noise management, and response to climate change. ADPHC is leading the project of Indoor Air Quality (IAQ), which aims to improve indoor air quality and health governance, policies and regulations, and strategic and operational planning.

For the purposes of this project, IAQ is defined as the totality of attributes of indoor air that affect a person's health and well-being. The project addressed IAQ in residential settings; public spaces such as school, government, retail, and corporate buildings; and workplace settings such as offices and other public, government, or corporate buildings where people work. The project did not address occupational exposure to hazardous airborne chemical substances, such as exposures in industrial, agricultural, or construction occupations, as addressing such pollutants would require different research settings.

Understanding IAQ and controlling indoor air pollutants is important to protect public health. Sources of indoor air pollutants include building materials, tobacco products, cleaning supplies, cooling systems, moisture, and outdoor sources such as radon or pesticides. If ventilation inside

a building is inadequate, these pollutants can build up in indoor air to levels that can have immediate or long-term health consequences.

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Contents

List of Abbreviations

ADPHC:	Abu Dhabi Public Health Center
EAD:	Environment Agency Abu Dhabi
IAP:	Indoor Air pollutants
ACGIH:	The American Conference of Governmental industrial Hygienists
UAE EBD:	United Arab Emirates Environmental Burden of Disease
PM:	Particulate matter
PRISMA:	Preferred Reporting Items for Systematic Reviews and Meta-Analysis
OSHAD:	Occupational Safety and Health Abu Dhabi
QCC:	Quality and Conformity Council
ESMA:	Emirates Authority for Standardization and Metrology
DMT:	Department of Municipalities and Transport
DUP:	Department of Urban Planning
DOH:	Department of Health
HAAD:	Health Authority Abu Dhabi
ETS:	Environmental Tobacco Smoke
ADESP:	Abu Dhabi Environmental Survey Program
HVAC:	Heat, ventilation, Air-conditioning System
ADM:	Abu Dhabi Municipality
EAA:	Executive Affairs Authority
CCP:	Comprehensive Colling Plan
EHSMS:	Environment, Health and Safety Management System
WHO:	World Health Organization
MoCCAE:	Ministry of Climate Change and Environment

FANR:	Federal Authority of Nuclear Regulation
ADIBC:	Abu Dhabi International Building Code
ADIMC:	Abu Dhabi International Mechanical Code
TLVs:	Threshold Limit Values
TG:	Technical Guidelines
ASHRAE:	American Society of Heating, refrigerating and air-Conditioning Engineers
VOCs:	Volatile Organic Compounds
ECAS:	Executive Council Affairs System
DCT:	Department of Culture and Tourism
PAF:	Population Attributable Factor
COPD:	Chorionic Obstructive Pulmonary Disease
SIDS:	Sudden Infant Death Syndrome
IARC:	International Agency for Research on Cancer

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Chapter 1: General Introduction to the Theses

1. Introduction

This paper is part of a project conducted by the Abu Dhabi Public Health Center (ADPHC) that included performing an institutional analysis of Abu Dhabi's existing capacities related to indoor air quality (IAQ). For the purposes of this project, IAQ is defined as the totality of attributes of indoor air that affect a person's health and well-being. The project addressed IAQ in residential settings; public spaces such as school, government, retail, and corporate buildings; and workplace settings such as offices and other public, government, or corporate buildings where people work. The project did not address occupational exposure to hazardous airborne chemical substances, such as exposures in industrial, agricultural, or construction occupations, as addressing such pollutants would require different research settings.

Understanding IAQ and controlling indoor air pollutants is important to protect public health. Sources of indoor air pollutants include building materials, tobacco products, cleaning supplies, cooling systems, moisture, and outdoor sources such as radon or pesticides. If ventilation inside a building is inadequate, these pollutants can build up in indoor air to levels that can have immediate or long-term health consequences.

The project conducted by the ADPHC aimed to better understand the IAQ landscape in the Emirate of Abu Dhabi and develop a framework for IAQ governance, policies, and regulations in the Emirate. The project also was intended to coordinate IAQ and health-related initiatives among the different concerned stakeholders in the Emirate via a well-stablished structure. The goal is to have a single established IAQ regulatory program that meets or exceeds international best practices and reduces burden of disease from indoor air pollutants by 2030; thus outcomes should focus on improving IAQ and health governance, policies and regulations, and strategic and operational planning.

2. Approach

The project developed a logical sequence to understand the current situation in Abu Dhabi, assess international best practices in IAQ governance, quantify the economic impacts of new regulations or programs, and update the IAQ module in the United Arab Emirates (UAE) Environmental Burden of Disease Model. The findings of these activities, along with the 2010 *National Strategy and Action Plan for Environmental Health: Indoor Air* and the 2014 *Annual Policy Brief: Enhancing Air Quality in Abu Dhabi*, were used to prepare a holistic regulatory framework for IAQ suited to Abu Dhabi's current governance and needs. For the sake of this paper, the following tasks are elaborated in chapters 2, 3, 4, and 5.

- Existing Institutional Arrangements and IAQ Requirements in the Emirate of Abu Dhabi (Chapter 2);
- Situational and Gap Analysis for Existing or Proposed Institutional Arrangements for IAQ and Health (Chapter 2);
- Stakeholder Surveys (Chapter 2);
- Situational and Gap Analysis for Existing or Proposed Testing and Monitoring Standards or Guidelines for IAQ in Abu Dhabi Emirate (Chapter 3);
- Review of the Scientific Evidence Base on the Link Between IAQ and Health (Chapter 4)
- Baseline Parameters and Health-Based Indicators and Targets for Indoor Air Quality (Chapter 4)

The primary government entity responsible for policy and regulation of IAQ in Abu Dhabi is the ADPHC. The mission of the ADPHC is to preserve the health of residents and guarantee worker safety in the Emirate. Furthermore, the Center is responsible for developing training programs to raise capacities related to public and preventive health. ADPHC prepares and implements awareness campaigns and educational programs related to public and preventive health. In coordination with other concerned entities, ADPHC conducts surveys and develops data and information collection mechanisms related to public and preventive health. The Abu Dhabi Occupational Safety and Health Center (OSHAD), which now resides within ADPHC, is responsible for collecting evidence and data related to serious workplace injuries and accidents, in liaison with concerned authorities, to determine the causes and reduce the risks.

The mission and responsibilities of ADPHC align to address IAQ. As the Abu Dhabi government entity accountable for all members of society's well-being and health, ADPHC has the appropriate expertise and is responsible for developing the governing structure, strategies, and standards to ensure all IAQ is protective of human health. While ADPHC has jurisdiction to preserve health, it must work with the Abu Dhabi Quality and Conformity Council (QCC) and the Emirates Authority for Standardization and Metrology (ESMA) to set IAQ standards for the Emirate. The Department of Municipalities and Transport (DMT) is also a vital stakeholder because it establishes requirements for building ventilation rates, temperature, and relative humidity. Environment Agency—Abu Dhabi (EAD) is another important partner for ongoing monitoring of IAQ and indoor air pollutants across the Emirate. Finally, non-governmental professionals in academia, the health sciences, and building construction and management will also have vital roles in developing and implementing the proposed governance structure.

3. Summary of covered tasks

1. **Existing Institutional Arrangements and IAQ Requirements in the Emirate of Abu Dhabi (Chapter 2)** provided a review of Abu Dhabi's current IAQ regulatory framework. The report prepared under this task lists policies and the government agencies that disseminated them, in areas including environmental protection, pollutant control, and building codes.
2. **Situational and Gap Analysis for Existing or Proposed Institutional Arrangements for IAQ and Health (Chapter 2)** reviewed the existing institutional arrangements in Abu

Dhabi Emirate. This review will be used as a foundation for the formulations of best practices for Abu Dhabi in three broad categories: (1) governance structure, including the standards in place and relationships between agencies; (2) monitoring and research, including ongoing data collection and developing professional IAQ expertise; and (3) public awareness, including campaigns to encourage beneficial behaviors and educate the public about IAQ. This was completed by surveying the concerned stakeholders.

3. **Review of Stakeholder Surveys in Indoor Air Governance, Operations, and Research (Chapter 2)** sought insights from relevant experts within Abu Dhabi's entities about existing institutional arrangements, research, monitoring, and general awareness of IAQ in Abu Dhabi Emirate. Representatives of local and federal government entities and research institutions provided information on which pollutants and IAQ issues are of concern, their understanding of Abu Dhabi's institutional capacity to regulate IAQ, barriers to improving IAQ governance, and how to overcome those barriers.
4. **Situational and Gap Analysis for Existing or Proposed Testing and Monitoring Standards or Guidelines for IAQ in residential and public buildings (Chapter 3)** provided a list of the nine highest priority indoor air pollutants (IAPs) in Abu Dhabi Emirate and enabled development of recommended maximum limits for these pollutants. The gap analysis synthesized the pollutants with serious health impacts identified in the literature review, pollutants identified by experts and stakeholders in the survey, and standards currently in place in Abu Dhabi on how each pollutant is regulated, including the maximum limit and the frequency and method of testing and monitoring for each pollutant.
5. **Review of the Scientific Evidence Base on the Link Between IAQ and Health (Chapter 4)** provided an updated review of the scientific evidence on the link between IAQ and human health, including modifications to the IAQ module in the UAE Environmental Burden of Disease Model. A systematic international literature review on the relationship between residential IAQ and human health and on assessments of exposure to indoor air

pollutants in residential settings was performed to update a previous review, published in 2013 as Chapter 5, “Burden of Disease From Indoor Air Pollution,” in the book *Environmental Burden of Disease Assessment: A Case Study in the United Arab Emirates*. The findings of that literature review were used to estimate the annual number of preventable illnesses and premature deaths attributable to indoor air pollution in Abu Dhabi, and the potential reduction in illnesses and deaths that would result from decreasing exposure to those pollutants.

6. **Baseline Parameters and Health-Based Indicators and Targets for IAQ (Chapter 4)** reviewed existing scientific literature about IAQ pollutants, including their common sources in indoor environments, the health issues they are known to cause, and the annual number of deaths and illnesses attributable to them in Abu Dhabi. It also estimated levels of pollutants the average person in Abu Dhabi is exposed to, suggested maximum target levels of each pollutant, and potential methods for reducing indoor pollutant exposure.

4. Findings

4.1 Stakeholder Involvement

The primary government entity responsible for policy and regulation of IAQ in Abu Dhabi is the ADPHC. The mission of the ADPHC is to preserve the health of residents and guarantee worker safety in the Emirate. Furthermore, the Center is responsible for developing training programs to raise capacities related to public and preventive health. ADPHC prepares and implements awareness campaigns and educational programs related to public and preventive health. In coordination with other concerned entities, ADPHC conducts surveys and develops data and information collection mechanisms related to public and preventive health. The OSHAD now resides within ADPHC. It is responsible for collecting evidence and data related to serious workplace injuries and accidents, in liaison with concerned authorities, to determine the causes and reduce the risks.

The mission and responsibilities of ADPHC align to address IAQ. As the Abu Dhabi government entity accountable for the well-being and health of all members of society, ADPHC has the appropriate expertise and is responsible for developing the governing structure, strategies, and standards to ensure all IAQ is protective of human health. Therefore, ADPHC is in position to lead the implementation of this Action Plan.

While ADPHC has jurisdiction to preserve health, it must work with the Abu Dhabi QCC and the ESMA to set IAQ standards for the Emirate. The DMT is a vital stakeholder because it establishes requirements for building ventilation rates, temperature, and relative humidity. EAD is an important partner for ongoing monitoring of IAQ and IAPs across the Emirate. Finally, non-governmental professionals in academia, the health sciences, and building construction and management will also have vital roles in developing and implementing the proposed governance structure.

ADPHC's institutional analysis revealed that several government entities are involved in some aspect of IAQ (e.g., the Abu Dhabi Department of Health [DOH], ADPHC, and EAD). However, no single government entity serves as the focal point to coordinate government efforts to improve air quality. For example:

Current Federal and Emirate environmental protection laws, regulations, and codes do not mandate IAQ assessment. Only one Federal environmental law sets general requirements for establishments and closed and semi-closed places that may affect human health and the environment. Still, it does not define any goals, tasks, or responsibilities related to IAQ.

The *National Strategy and Action Plan: Indoor Air* (2010) established national initiatives and Key Performance indicators KPIs to reduce public health impacts from IAP, but no regulatory authority has responsibility for developing, implementing, and assessing the action plan to address indoor air.

Annual Policy Brief: Enhancing Air Quality in Abu Dhabi (2014) recognizes the importance of linking IAQ and public health and the need for continued education and awareness campaigns regarding the human health risks associated with indoor air pollution. The *Policy Brief* calls for an improved regulatory framework, including mandatory requirements for pollutant-emitting construction materials, ventilation, duct maintenance, and smoking in public spaces.

In 2014, EAD, ADPHC, and other governmental entities implemented aspects of the *National Strategy and Action Plan* and *Annual Policy Brief*. However, there has been no consistent and integrated approach to achieve the IAQ targets and improvements outlined in these documents. Abu Dhabi Emirate would benefit from having a single regulatory authority assume responsibility for coordinating efforts to develop standards, certifications, regulatory requirements, and compliance assurance methods.

4.2 Priority Pollutants and Associated Health Impacts

Nine priority pollutants requiring standards were identified based on the international best practice review, stakeholder surveys, and scientific health literature review:

- Particulate matter < 2.5 microns ($PM_{2.5}$)
- Particulate matter < 10 microns (PM_{10})
- Radon
- Formaldehyde (HCHO)
- Benzene
- Environmental tobacco smoke (ETS)
- Incense combustion products

- Mold
- NO_2 from natural gas stoves.

Note that while mold has been studied globally, the relevant standards are specified in terms of ventilation rates, temperature, and relative humidity. Similarly, note that while the health effects of natural gas stoves have been studied globally and international standards are specified for NO_2; health studies often treat natural gas stoves as a proxy for NO_2.

4.3 Action Plan

Based on the conducted literature review and the IAQ institutional arrangements gap analysis, an action plan is proposed to coordinate IAQ and health in Abu Dhabi Emirate. This action plan focuses on improving IAQ and health governance, policies and regulations, and strategic and operational planning. New or amended regulations, policies, or other programs proposed would apply to both residential and public spaces.

ADPHC should serve as the lead entity, as it has the appropriate mission, expertise, and experience. All entities with work related to IAQ in the Abu Dhabi government should acknowledge and announce ADPHC's leadership role. ADPHC in turn should work closely with QCC, ESMA, DMT, EAD, and the other governmental partners who have legislated responsibilities for IAQ. Besides its mission to preserve the health of Abu Dhabi citizens and its roles in tracking public health and raising awareness, ADPHC should add to its responsibilities ensuring that the full IAQ action plan is accomplished in the next 10 years. This feat will require coordinating, convening, tracking, and reporting.

The following sections outline the recommended actions to be followed in accordance with the proposed plan.

4.3.1 Initial Actions

Establish Leadership, Higher Committee, and IAQ Taskforce. ADPHC should be established as the lead agency for IAQ in Abu Dhabi and the agency responsible for implementing the Action Plan. A Higher Committee on IAQ is proposed to be created with the authority to delegate, monitor, and enforce the Action Plan as an effective mechanism to further ensure implementation. Such a committee was recommended in the 2014 Annual Briefing. ADPHC would routinely report progress and next steps to the committee, which in turn would inform the Executive Council. An IAQ taskforce comprising Federal and Emirate government stakeholders should be developed to serve as a coordinating and convening body that monitors implementation of the 10-year Action Plan. It should have clear definitions of roles and responsibilities to ensure alignment and avoid duplicative efforts. The IAQ Task Force is proposed to monitor progress on the action plan steps, noting successes and working to overcome challenges. The Task Force will include members and representatives from the below entities and any others as appropriate.

- Department of Health—Abu Dhabi (DOH)
- Environment Agency—Abu Dhabi (EAD)
- Abu Dhabi Department of Municipalities and Transport (DMT)
- Abu Dhabi Quality and Conformity Council (QCC)

Establish an Advisory Committee and working groups. The IAQ Task Force is to establish an Advisory Committee to provide technical advice. Other Advisory Committee tasks would include:

- Developing draft standards and guidance documents;
- Indicating where public health campaigns are needed;
- Determining guideline values for indoor air pollutants, ventilation systems, and household products that emit pollutants for the Emirate;
- Assisting with preparing a research agenda;

- Reviewing the status of air quality expertise and training within the Emirate; and
- Providing other advice as requested.

Technically trained individuals from academia, the health care community, environmental health experts, civil and building engineers, and other relevant professionals shall comprise the Advisory Committee. The Committee may organize working groups to address specific tasks. These working groups should draw not only on Advisory Committee members' expertise but also on subject matter experts as needed. The Advisory Committee may form ad hoc working groups as needed.

4.3.2 Governance Actions

A. Structure

Set roles and responsibilities. The IAQ Task Force will articulate roles and responsibilities for compliance and enforcement of IAQ standards, and monitoring of IAPs, identifying which Federal or Emirate organizations are involved and how these organizations should collaborate. The Task Force should set specific goals, tasks, and responsibilities for each organization related to IAQ.

Describe the current IAQ regulatory system. The IAQ Task Force should clearly and concisely describe the current IAQ regulatory system responsible for setting standards, certifications, requirements, and compliance assurance methods and recommend any needed changes or updates to the system.

Review and update how IAQ standards are monitored. The IAQ Task Force should update the process and procedures to monitor the attainment of existing standards. The monitoring system must specify the frequency of measurements, how and to whom to report quantities detected, who shall bear monitoring costs, and any incentives for compliance or consequences for noncompliance.

Review and update how IAQ standards are enforced. Methods of enforcing existing IAQ standards should be updated or revisited by the IAQ Task Force. Parties (building owners, residents, public officials, etc.) are responsible for complying with IAQ standards and correcting noncompliance.

B. Standards and Guidance

Develop technical guidance. The IAQ Advisory Committee should develop technical guidance documents to support the IAQ Task Force. Technical guidance would be provided for collecting IAP measurements and conducting risk assessments.

Develop pollutant limits. The IAQ Advisory Committee should recommend to the IAQ Task Force mandatory minimum levels for the nine priority pollutants and other IAQ components legally required for many buildings. The recommended limits should specify that responsible parties (e.g., building owners, residents, public officials) must comply with these IAQ standards. The IAQ Advisory Committee may propose non-mandatory limits more protective of human health, and provide incentives for buildings that meet them, perhaps as part of Estidama (Arabic for “sustainability”) certification.

Set standards. The IAQ Task Force should work with the QCC to set standards for mandatory maximum levels of the first nine priority pollutants and other components of IAQ that buildings should be legally required not to exceed. To the extent possible, IAQ standards should apply to schools and to all public, residential, and commercial buildings. Standards should always meet or exceed international standards.

Expand the Estidama voluntary certification program. The IAQ Task Force should work with ESMA to consider expanding Estidama's voluntary certification program to encourage compliance with pollutant guidelines stricter than the mandatory minimum levels. The IAQ Task Force should consider expanding incentives for building owners to seek certification.

Develop certification guidelines for low-emission household products. The IAQ Task Force should work with the QCC to develop and improve certification guidelines for all household products sold in Abu Dhabi. All products, including imported and domestically produced products, should be certified as being made of low-emission materials. Guidelines should be prioritized for products containing benzene and formaldehyde.

Require CO monitors. Natural gas stoves are a major source of both residential CO and NO_2 exposure. The IAQ Task Force should work with the DMT to require CO monitors in any residence with natural gas cooking.

4.3.3 Monitoring Actions

Monitor smoking and incense use. The ADESP (Environmental Survey Program) should track the prevalence of indoor smoking and incense burning in schools and in public, residential, and commercial buildings to assess baseline levels and improvements.

Develop exposure assessments. The ADPHC should work with EAD and local researchers to use ADESP data to update or develop IAP exposure assessments in schools and in public, residential, and commercial buildings. Measurements of major indoor air contaminants, including but not limited to the priority pollutants, are necessary to understand the health risks associated with IAQ. The highest priority environmental exposure assessments include those focused on:

- Environmental tobacco smoke, which causes over 30,000 attributable healthcare episodes of cardiovascular disease, 25,00 lower respiratory tract infection episodes in children, and over 20,000 asthma episodes in children per year;
- PM_{10}, which causes over 45,000 attributable healthcare episodes of childhood asthma;
- Incense combustion products, which cause the largest number of attributable deaths of the nine priority pollutants;
- Benzene, which is the only priority pollutant without measurements specific to the United Arab Emirates; and
- Mold, which has exposure assessment data from 2002 that should be updated.

Quantify health risks. The ADPHC should work with EAD and local researchers to quantify health risks associated with low IAQ and link IAQ experienced in Abu Dhabi with environmental health impacts.

Quantify economic benefits. The ADPHC should work with local researchers and economists to quantify the economic benefits of reducing the levels of indoor air pollutants with an expanded regulatory impact analysis.

Update the IAQ module in the environmental burden of disease model. The ADPHC should maintain and update parameters in the UAE Environmental Burden of Disease Model.

4.3.4 Research and Expertise Actions

Establish an IAQ research agenda. The IAQ Task Force should collaborate with local universities to establish and continually update an IAQ research agenda.

Share IAQ data. The IAQ Task Force should collaborate with local universities to publicly share de-identified data on IAQ issues to the greatest extent possible.

Improve government-academia collaboration. The IAQ Task Force should collaborate with local universities to improve cooperation and communication between government and academia.

Enhance research funding. The IAQ Advisory Committee should review existing IAQ research funding mechanisms in the Emirate and identify gaps where additional research funding is needed. The amount of funding will depend on the Advisory Committee's review.

Enhance IAQ expertise and training. The IAQ Advisory Committee should determine existing IAQ expertise and training programs in Abu Dhabi and identify gaps in experience or training. The IAQ Task Force should support programs to enhance IAQ expertise and training, such as graduate scholarships or new training programs.

4.3.5 Public Awareness and Education Actions

Determine public awareness and education needs. The IAQ Advisory Committee should provide technical guidance to ADPHC on potential topics and information, such as the health risks of poor IAQ and behaviors that impact indoor air.

Conduct public awareness and education campaigns. The ADPHC should conduct public health campaigns on the health risks of poor IAQ and behaviors that impact indoor air, and who they can contact to report IAQ concerns. Particularly relevant topics for Abu Dhabi would include campaigns on the risks of exposure to secondhand smoke from tobacco products (including shishas), and to incense burned indoors without proper ventilation. Development of campaigns targeting children should involve the Abu Dhabi Department of Education and Knowledge.

Train property management companies. The IAQ Task Force should collaborate with the DMT to establish a program to train property management companies on IAQ standards and enforcement. The training program should address testing, monitoring, improving IAQ in their buildings, best practices for maintaining indoor environmental health, and any incentives available for meeting recommended guidelines.

Chapter 2: Assessment and Review of Existing Local Governance Structures, Policies and Regulations, Guidelines, Strategies Related to IAQ and Health:

"A high-level review of Abu Dhabi's institutional arrangements related to IAQ"

1. Introduction

Indoor air quality (IAQ) is defined as the totality of attributes of indoor air that affect a person's health and well-being (Brown, 1997). Indoor air pollution causes multiple health impacts, ranging from acute conditions such as sensory irritation, to chronic, potentially life-threatening conditions such as cancer and cardiovascular disease (Logue et al., 2012; Gibson, et al., 2013). Among 14 environmental risks to public health considered in the United Arab Emirates, stakeholders ranked indoor air pollution as the second highest priority (Gibson and Farah, 2012). Indoor air pollution is considered a high priority based on several factors:

1. The public has high potential exposure to indoor air pollutants owing to the significant amount of time spent indoors.
2. Indoor air pollution is the second leading environmental cause of excess death in the UAE (Ref.: The State of Environmental Health in the UAE report, 2009);
3. Several potential sources of pollutants have been identified in indoor environments

The Emirate of Abu Dhabi has a clear vision of how to reduce preventable illnesses and death from exposure to environmental pollutants. This vision includes an indoor air quality strategy that The Department of Health—Abu Dhabi (DOH) and Abu Dhabi Public Health Center (ADPHC) are developing in close cooperation with concerned stakeholders (mediated by Environment Agency—Abu Dhabi [EAD]).

To further regulate the issue of IAQ, indoor air pollutants needs to be identified and prioritized. The most frequent indoor air pollution sources are:

1. Building construction materials (e.g., concrete, stone, wallboard, paint, and insulation);
2. Building contents (e.g., heating, furnishing, natural gas, and water service);
3. Human metabolic activity;
4. Human activities (e.g., environmental tobacco smoke [ETS], cooking fumes, incense burning, air fresheners, candles, cleaning products);
5. Highly humid environments that result in surface condensation and growth of mold, fungi, and pathogenic bacteria like Legionella.
6. Outdoor air pollution that filters through open windows. Rocks and soil can emit radioactive radon gas to indoor environments through cracks and gaps in solid floors and walls (Hollowell, 2011; Koo and Ho, 1996; Gibson, et al. 2013; Maroni, et al. 1995).

These sources pollute the indoor air with several types of pollutants, such as SO_2, NO, NO_2, O_3, CO, CO_2, NH_3, Pb, HCN, hydrocarbonates, particulates, radon gas, formaldehyde, mercury, sulfates, organics, odors, fluorocarbons, and vinyl chloride hydrocarbons (Hollowell, 2011). Moreover, radioactivity in indoor environments can result from both the natural environment and from contaminated imported materials.

2. Indoor Air Quality in the Emirate of Abu Dhabi

The Emirate of Abu Dhabi has already seen great achievements in improving IAQ in various ways and at different levels. The National Strategy and Action Plan for Environmental Health 2010 for the United Arab Emirates is one of these great achievements; it provides, on a national level, a clear and comprehensive strategy and outlines a wide range of activities to improve environmental health in general, and IAQ in particular.

Another example is the study “The State of Environmental Health in the United Arab Emirates” which was conducted jointly in collaboration with the EAD, UAE University, University of North Carolina (United States [U.S.]), the RAND corporation, the Norwegian Institute for Air Quality Research, and Resources for the Future, with strategic support from the World Health Organization Regional Center for Environmental Health Activities, Amman, Jordan. This study describes the state of environmental health in the UAE and provides further information on the health risks related to IAQ.

The book *Environmental Burden of Disease Assessment – a case study in the United Arab Emirates*, had input from many environmental scientists inside and outside the UAE and is a result of the first–ever effort by a nation to commission a comprehensive model to estimate the national burden of disease from environmental pollution (Gibson, et al. 2013). Also, several surveys and scientific studies were conducted to analyze the indoor air pollution types and levels in the Emirate of Abu Dhabi, and to understand its causes and effects. Some examples include the “Hazard assessment of UAE incense smoke” study (2013) and “Environmental Risks to Public Health in the United Arab Emirates: A Quantitative Assessment and Strategic Plan” research project (2012).

In 2010, the Abu Dhabi Urban Planning Council (UPC) banned the import and use of asbestos and lead in products that may be used in residential and commercial environments. This has been a large step towards reducing exposure to two well-characterized materials that are commonly associated with numerous chronic and potentially life-threatening health conditions. This step came after passing of the Ministerial Decree No. (42) in 2008 to regulate procedures for asbestos pipe production and disposal of asbestos waste, and passing of the Federal Cabinet Resolution No. (39) in 2006 to prohibit import, production, and use of asbestos.

In 2012 the Abu Dhabi Safety and Occupational Health Center (OSHAD, part of ADPHC now) issued the code of practice EHS R1 COP 1.10 for the management of asbestos-containing materials.

Regulation for management of existing radiation exposure situations, being prepared by Federal Authority for Nuclear Regulation (FANR) according to the best international practice, is providing legal grounds for regulating:

1. Exposures due to contamination of area by residual radioactive material;
2. Exposures due to radon and its progeny in workplaces, dwellings, and other buildings with high occupancy factors for members of the public;
3. Exposures due to commodities, including construction materials, food, and drinking water.

The Abu Dhabi Quality and Conformity Council (QCC) developed Abu Dhabi's certification schemes for exterior and interior paints, adhesives, sealants, carpets, and hard flooring, which are in line with international standards and contribute to improvements in indoor environment quality and the material emissions requirements published by Estidama.

The UPC Estidama Buildings and Communities Program has introduced specific requirements for building construction and renovation. These requirements ensure high-quality ventilation systems and aim to ensure high IAQ with regard to harmful emissions from construction material, furniture, and paints. Also, UPC reviews new building applications for compliance with Estidama standards and audits construction sites to ensure measures are implemented.

The Department of Municipalities and transport (DMT) has contributed by introducing three municipal codes:

1. The Abu Dhabi International Mechanical Code, which regulates IAQ for buildings by addressing the design and installation of quality heating, ventilation and air conditioning (HVAC) systems and the associated exhaust, drainage, and ductwork system;
2. The Abu Dhabi International Energy Code, which aims to ensure airtight façade systems to reduce infiltration of moisture and contaminants that may lead to the development of fungi such as mold, a key contributor to poor IAQ;
3. The Abu Dhabi International Building Code, which aims to ensure that all indoor spaces are adequately ventilated. The building code also regulates sound transmission to ensure a more peaceful internal environment.

The Abu Dhabi City Municipality (ADM) conducted an energy efficiency study for residential buildings in sector E02-3. As part of this project, IAQ was investigated during January 2012 in six buildings in the sector, including three residential, one commercial, one school building, and one mosque. The primary goal of this study was to define the status of existing buildings with respect to determinants of IAQ and occupant perceptions. ADM established a building maintenance section to look after each building's maintenance, safety, health, and environment. This section is responsible for implementation of relevant codes and requirements.

Led by the Executive Affairs Authority (EAA), the government of Abu Dhabi recently developed a Comprehensive Cooling Plan (CCP) and is now in the process of implementing it. Among other objectives, the CCP aims to promote and improve the maintenance of air conditioning systems throughout Abu Dhabi, which will have a positive impact on IAQ as well.

Several federal and local regulations for the United Arab Emirates and the Emirate of Abu Dhabi are intended to control the management and improvement of IAQ. Federal Law No. 24 of 1999, articles 55 and 56, and the Ministers Cabinet Decree No. 12 of 2006, articles 12 and 13 are mandating concerned parties to ensure adequate ventilation in the workplace, as well as public and touristic places, and to take the necessary precautions and measures to prevent leakage or emission of air pollutants.

With the 2012 Abu Dhabi Environmental Health And Safety (EHS) Management System (EHSMS) Regulatory Framework, a technical guideline for occupational and IAQ monitoring was established for implementation in all workplaces in EHSMS sectors and entities (9 sectors are covered in the Emirate of Abu Dhabi). For health care facilities licensed by the DOH—Abu Dhabi, the DOH Health Sector EHSMS sets standards for IAQ in accordance with applicable federal and local laws and regulations, and international best practice. These standards aim to ensure the protection of the health and safety of employees, patients, visitors, and contractors in health care settings and the surrounding community.

The prohibition of smoking in closed public places by Federal Law No. (15) of 2009 was an important step that the United Arab Emirates took to protect the public health from ETS and to improve IAQ. According to World Health Organization (WHO) studies, ETS causes 600,000 premature deaths per year around the globe. There are more than 4,000 chemicals in tobacco smoke, of which at least 250 are known to be harmful and more than 50 are known to cause cancer. Based on that, appropriate measures have been introduced in buildings designed as per Estidama standards to eliminate or minimize exposure of building occupants to the harmful effects of ETS.

Several entities in the Emirate of Abu Dhabi have made a considerable effort to raise awareness of the health risks of tobacco by implementing educational and awareness campaigns. For the Emirate of Abu Dhabi, DOH and ADPHC have taken an early leading role in tobacco control. In 2007, DOH was the first governmental entity in the Emirate of Abu Dhabi to issue a No Smoking Policy for Workplaces and Public Places, as well as a Policy on Smoke-free Healthcare Facilities, and several tobacco control-related standards (e.g., on smoking cessation counselling services, prohibition of tobacco product sales to minors, prohibition of tobacco product sales through vending machines, and a ban on tobacco advertising, promotion, and sponsorship).

Also in 2007, DOH implemented the first large-scale governmental tobacco control public awareness campaign in the Emirate of Abu Dhabi, “Abu Dhabi Says No to Tobacco”, which was aligned with the 2007 WHO tobacco control campaign and launched on World No Tobacco Day, May 31st, 2007. Since 2009 DOH has developed tobacco control action plans in line with UAE Tobacco Control Federal Law No. 15 of 2009 and has been contributing to the development of a federal Executive Decree (by-law) on Tobacco Control, which was approved in June 2013 by the Cabinet of Ministers. The Tobacco Control Public Health Program was ranked by DOH in 2011 and 2012 as a third priority public health program for the community.

3. Summary of Current Regulation

The UAE and the Emirate of Abu Dhabi governments issued several laws and regulations aimed at ensuring IAQ standards.

1. Federal Regulations

- Federal Law No. (24) of 1999, articles 55 to 57 mandate the protection and development of the environment related to IAQ.
- The Federal Cabinet of Ministers Decree No. (12) of 2006 concerning the protection of air from pollution in Articles 12 and 13.
- Federal Law No. (15) of 2009 for controlling tobacco among others, Articles 5, 7, 8 and 11.

- Ministerial Decree No. (42) of 2008 on the control of asbestos pipe production and control of procedures for disposing asbestos product waste relates to IAQ with articles 1, 2, and 3.
- The Federal Cabinet of Ministers Decree No. (39) of 2006 prohibits import, production, and use of asbestos in articles 1 & 2.

2. ***The Emirate of Abu Dhabi Regulations and Technical Guidelines***

- Urban Planning Council Estidama Building Requirements (Pearl Building Rating System: Design & Construction, Version 1.0, April 2010):
  - LBi-R2: Smoking Control. To eliminate or minimize exposure of building occupants to the harmful effects of tobacco smoke.
  - LBi-1: Ventilation Quality. To promote the provision of building systems that support the well-being and comfort of occupants by providing sufficient outside air ventilation.
  - LBi-2.1: Material Emissions: Adhesives & Sealants. Confirms the use of low-emission adhesives and sealants to encourage the desirability of these spaces in relation to improved occupant health.
  - LBi-2.2: Material Emissions: Paints & Coatings. Confirms the use of low-emission paints and coatings to encourage the desirability of these spaces in relation to improved occupant health.
  - LBi-2.3: Material Emissions: Carpet & Hard Flooring. Confirms the use of low-emission flooring systems to encourage the desirability of these spaces in relation to improved occupant health.

- LBi-2.4: Material Emissions: Ceiling Systems. Confirms the use of low-emission ceiling systems to encourage the desirability of these spaces in relation to improved occupant health.
- LBi-2.5: Material Emissions: Formaldehyde Reduction. To mitigate the health risks associated with formaldehyde in building materials and products.
- LBi-3: Construction Indoor Air Quality Management. To implement construction practices that promote a high degree of indoor air quality for construction workers and building occupants.
- LBi-4: Car Park Air Quality Management. To facilitate the provision of adequate air quality within enclosed car parks.
- SM-R1: Hazardous Materials Elimination. To eliminate exposure of building occupants to asbestos and minimize toxic effects of chromated copper arsenate-treated timber on people and the environment.

- DOH (previously HAAD) Public Health Policy Ban on Tobacco Advertising, Promotion and Sponsorship in the Emirate of Abu Dhabi (August 2007);
- DOH (previously HAAD) Public Health Policy on Sale of Tobacco Products to Minors and Through Vending Machines (July 2007).

Part A: Existing Institutional Arrangements and IAQ Requirements in the Emirate of Abu Dhabi

1. Introduction

The Abu Dhabi Public Health Center (ADPHC) is carrying out an operational review of Abu Dhabi's current indoor air quality (IAQ) capabilities. For the purposes of this project, IAQ is defined as the totality of indoor air characteristics that influence the health and well-being of an individual. This project addresses IAQ in residential settings; public spaces such as school, government, retail, and corporate buildings; and workplace settings such as offices and other public, government, or corporate buildings where people work. This project does not address occupational exposure to hazardous airborne chemical substances in industrial, agricultural, or construction settings.

Understanding IAQ and controlling indoor air pollutants is important to protect public health. Construction materials, tobacco products, cleaning equipment, ventilation systems, moisture, and outside sources such as radon or pesticides are sources of indoor air pollutants. When ventilation inside a building is inadequate, these pollutants can build up in indoor air to levels that can have immediate or long-term health implications.

This chapter of the project aims to better understand the IAQ landscape in the Emirate of Abu Dhabi that can be used as a foundation for the development of a framework for IAQ governance, policies, and regulations. The purpose of this report is to provide an overview of the existing IAQ regulatory framework.

2. Approach

The UAE federal government and Abu Dhabi have enforced laws on asbestos and air quality, public use of tobacco, and closed and semi-closed locations since 1999. However, it was not until the 2009 State of Environmental Health in the UAE that the quality of indoor air was examined more closely.

At the same time, the Abu Dhabi Department of Health (DOH) issued recommendations to improve home IAQ. The DOH recommendations identify sources of indoor air pollution and recommend mitigation measures to reduce contaminant levels (Indoor Air Quality at Home: Recommendations to protect your family's health, undated).

In 2010, the federal government and Abu Dhabi Emirate developed a robust National Strategy and Action Plan for Environmental Health to reduce the public health impacts of pollution. The National Strategy, which was escalated by the Environmental Agency—Abu Dhabi (EAD) to the Abu Dhabi Executive Council, identified thirteen categories of environmental risks to public health and prioritized IAQ.

Moreover, multiple Abu Dhabi government agencies (e.g., DOH, EAD DMT) separately developed policies, guidelines, certifications, and codes to achieve some of the IAQ targets outlined in the National Strategy. The Abu Dhabi Center for Occupational Safety and Health (OSHAD previously), now part of the ADPHC, was established in February 2010 to, among other things, measure and monitor indoor air pollution to ensure occupational safety and health in the workplace.

Also, the Estidama program ("sustainability" in Arabic) is an Abu Dhabi government initiative to ensure that all communities, buildings, and villas under design, construction, and operation balance the four pillars of environmental, economic, cultural, and social well-being. The program's "Pearl Rating System" contains mandatory conditions and guidance. Thus, new projects and developments can receive a design, construction, and operational rating that increases sustainability and improves IAQ (note: no clear enforcement mechanism is in place, nor are there currently reward systems—these areas of concerns are addressed in the recommendations).

A regulatory program and standards are in place for occupational air quality (Table 1), but there are no general governance, policies, or regulations for IAQ. As the Abu Dhabi government agency responsible for the well-being and health of all members of society, ADPHC is accountable for developing the governing structure, strategies, and standards to ensure that all IAQ is protective of human health (enforcement and penalty system should be established and enforced).

Table 1: An overview of the current Abu Dhabi Indoor Air Quality regulatory framework by issue area and description

Name	**Entity (Purpose)**
Environmental Protection (General and mandatory)	
Federal Law No. (24) of 1999	MoCCAE (for environmental protection of establishments and closed and semi-closed places that may affect human health and the environment)
Abu Dhabi Law No. (16) of 2005	EAD (for environmental protection that could affect human health and the environment)
Tobacco use (Mandatory)	
Federal Law No. (24) of 1999	MoCCAE (prohibits smoking unless licensed by competent authority)
Federal Law No. (15) of 2009	DMT (expands smoking prohibition)
Cabinet Decision No. (24) of 2013	DMT (establishes conditions for designated smoking areas)
Estidama, 2010	DMT (establishes mandatory requirements to reduce exposure to tobacco smoke)
Asbestos (Mandatory)	
Cabinet Decision No. (39) of 2006	MoCCAE (bans importation, use, and production of asbestos board)
Ministerial Decision No. (42) of 2008	MoCCAE (establishes requirements for disposal of asbestos products)

AD EHSMS RF, Codes of Practice (EHS RI CoP #1.10): Management of Asbestos Containing Materials, July 2016	OSHAD (removal and management of asbestos-containing materials from existing buildings and structures)
ADIBC	DMT (prohibits use, movement, and repair of asbestos products in new buildings)
Estidama	DMT (demonstration of no asbestos-containing materials in new buildings and removal of them from existing buildings seeking a permit to renovate)
Radon (Mandatory)	
Regulation for Existing Exposure Situations (FANR-Reg-19), undated	Sets reference levels, protection strategies, and remedial action requirements for radon in dwellings, buildings, and the workplace.
Building Codes (Mandatory)	
Abu Dhabi International Building Code (ADIBC), 2013	DMT (building construction requirements)
Abu Dhabi International Mechanical Code (ADIMC), 2013	DMT (sets minimum standards for mechanical systems, appliances, and ventilation systems)
Estidama, 2010	DMT (establishes mandatory requirements for ventilation, HVAC, Legionella prevention, and material emissions for schools)
Occupational Air Quality	
Abu Dhabi Occupational and Health System Framework (OSHAD-SF), Occupational Standards and Guideline Values, Version 3.0 (July 2016)	OSHAD (formerly) established non-mandatory standards and guideline values for the presence of chemical substances in occupational air. The Abu Dhabi Executive Council may change any occupational air threshold limit value to a mandatory standard.
Abu Dhabi Occupational and Health System Framework (OSHAD-SF), Technical Guideline, Occupational Air	OSHAD (formerly) issued a technical guideline to help entities determine the objective of an occupational air quality assessment and provide guidance on how to monitor air quality and collect air samples of indoor and workplace air.

Quality Management, Version 3.1 (Feb. 2019)	
Standards and Specifications (Mandatory)	
Federal Law No. (28) of 2001	ESMA (mandatory product certification scheme to ensure the safety and quality of products sold in the UAE)
Facilities Policy Manual, Chapter 9 – Health and Safety, DOH Policy for Healthcare Facilities, Occupational and Indoor Air Quality (February 2009)	DOH requires all private and public healthcare facilities to monitor occupational and indoor air quality and eliminate risks when any occupational and indoor air quality standard is exceeded. The policy incorporates separate guidance for conducting a risk assessment of chemical hazards in healthcare facilities.
Ambient Air Emissions, Indoor and Occupational Air Quality Management (Standard) (03/07/2011)	DOH established indoor and occupational air quality requirements, standards, and monitoring requirements for Nominated Healthcare Providers in Abu Dhabi Emirate.
Indoor Air Quality Policies (Non-mandatory)	
National Strategy and Action Plan for Environmental Health United Arab Emirates (2010)	EAD, DOH, Dubai Health Authority, Ministry of Health and prevention (MOHAP), and MoCCAE (establishes priorities and targets to improve indoor air quality)
2014 Annual Policy Brief on Enhancing Air Quality in Abu Dhabi	DOH and EAD (seeks improved regulatory framework for and enforcement of indoor air quality requirements)
Indoor Air Quality Initiatives (Voluntary)	
Estidama, 2010	DMT (establishes voluntary measures to improve ventilation and air circulation, use materials with low volatile organic compound content and no formaldehyde, and improve thermal control)
Conformity certificates	ESMA and QCC (voluntary use of construction materials and consumer products that lower impact on indoor air quality)

Abbreviations: DMT, Department of Municipalities and Transport; DOH, Department of Health; EAD, Environment Agency—Abu Dhabi; ESMA, Emirates Authority for Standardization and Metrology; HVAC, heating, ventilation and air conditioning; MoCCAE, Ministry of Climate Change and Environment; OSHAD, Occupational Safety and Health—Abu Dhabi; QCC, Quality and Conformity Council.

3. Findings

3.1 Environmental Laws and Decrees

3.1.1 General Environmental Laws

A. Federal

The Federal Ministry of Climate Change and Environment (MoCCAE) controls air pollution in tourism, transportation, any other establishment, and closed or semi-closed public spaces that may affect human health or the environment (Federal Law No. (24) of 1999, Article 2). MoCCAE and EAD may issue environmental standards to control pollution and protect the environment (Federal Law No. (24) of 1999, Article 10).

IAQ (i.e., air circulation, cleanliness, and appropriate temperature) for tourist, transportation, establishments, and closed or semi-closed public spaces are maintained by having adequate ventilation relative to the size and capacity of an establishment (Federal Law No. (24) of 1999, Articles 55 and 56, and Federal Cabinet Decree (12) of 2006, Article 13). Construction licenses issued by MoCCAE or EAD shall include the terms and conditions to achieve adequate ventilation for closed and semi-closed public places (Federal Cabinet Decree (12) of 2006, Article 13).

B. Abu Dhabi Emirate

IAQ is not specifically discussed by the law creating EAD and its powers, Abu Dhabi Law No. (16) of 2005. However, without first obtaining a license or using products, equipment, or devices that endanger humans and the environment, institutions and individuals cannot conduct any action that could impact the lives of human beings or the environment (Abu Dhabi Law No. (16), Art. 14).

3.1.2 Tobacco use

Table 2: Tobacco use-related regulations (6 regulations)

No.	Law	Description
1	Federal Law No. (24) of 1999, Article 57	Federal law prohibits smoking in transportation facilities, elevators, and closed public and tourism establishments, unless allowed by license
2	Federal Law No. (15) of 2009 and its implementing regulation Cabinet Decision No. (24) of 2013	Bans smoking in closed public places, houses of worship, educational institutions, and health and sports facilities
3	Federal Law (15) of 2009, Articles 7 and 11	Closed public places, cafes, and other establishments serving tobacco products may have designated smoking areas if they meet specified conditions
4	Cabinet Decision No. (24) of 2013, Article 11, which implements Federal law No. (15)	Expands smoking prohibition to health and pharmaceutical facilities, public transport and adjacent terminals and waiting areas, entertainment and leisure facilities, such as theatres, and means of transporting food, petroleum, medicine and health products
5	Cabinet Decision No. (24) of 2013 Article 12	Details requirements for designated smoking areas (e.g., location of the designated area, size and capacity, use of automatic doors, and ventilation requirements) in enclosed public spaces.
6	Estidama, section LB1-R2, Smoking Control	1. Measures and plans to reduce exposure to tobacco smoke including prohibiting smoking throughout buildings, establishing smoke-free zones outside of entrance air intakes and operable windows, and locating designated smoking areas away from public use areas or pedestrian walkways 2. Sealing the perimeters of residential units and installing weather-stripping on internal doors 3. Smoking is prohibited in all school buildings and on school grounds

3.1.3 Asbestos

Table 3: Asbestos-related regulations (4 regulations)

No.	Level	Description
1	Federal	Federal Cabinet Decree No. (37) of 2001, which contains regulatory requirements for the UAE, banned the import, use, and production of asbestos board in 2006 (Cabinet Decision No. (39) of 2006), and Ministerial Decision No. (42) of 2008 outlined requirements for the disposal of asbestos products.
2	Abu Dhabi	1. Existing buildings: As part of the Abu Dhabi Occupational Safety and Health System Framework, the Abu Dhabi Occupational Safety and Health Center (OSHAD) issued a Code of Practice (CoP), 1.10 – Management of Asbestos Containing Materials, Version 3.0, July 2016, setting forth procedures for the removal and management of asbestos-containing material (ACM). Although OSHAD requirements are generally applicable to workplaces, private residences seeking a building permit and those who control through contract or tenancy non-domestic premises, including commercial, industrial, and residential apartments, are required to have the building surveyed by a licensed asbestos consultant to determine whether asbestos or ACM is present (CoP, 1.10 – Management of ACM, Version 3.0, July 2016). If sampling is impractical, the material shall be presumed to contain asbestos and handled and removed in accordance with the CoP's requirements. If a building or residence contains ACM, a risk management and asbestos management plan per the CoP is required (CoP, 1.10 – Management of ACM, Version 3.0, July 2016). The Asbestos Surveying Consultant must follow the CoP's general requirements for removing asbestos, monitoring air quality, and decontamination (Sections 3.15-3.25, CoP, 1.10 – Management of ACM, Version 3.0, July 2016). Asbestos and ACM removed from existing buildings must follow the waste disposal, removal, and decontamination processes and procedures set forth in Sections 3.26-28, CoP, 1.10 – Management of ACM, Version 3.0, July 2016). In addition, ACM are hazardous wastes per Law No. (21) of 2005 that must be handled

		and disposed of according to Tadweer's Technical Guidelines (CWM TG #08) for the Management of Asbestos and Asbestos Containing Material in the Emirate of Abu Dhabi.
		2. New buildings: The Abu Dhabi International Building Code (ADIBC) prohibits the use, movement, alteration, repair, and demolition of any ACM in any building or structure (ADIBC, 104.9.2). An Estidama Pearl 1 rating requires a demonstration that (1) no ACMs are used within a development, (2) ACMs have been removed from a renovated building (Estidama, SM-R1), and (3) any suspended ceiling system be free of asbestos (Estidama, LBi-2.4: Material Emissions: Ceiling Systems).

3.1.4 Radon

The Federal Authority for Nuclear Regulation (FANR) established reference levels for radon in dwellings, buildings, and workplaces (Regulation for Existing Exposure Situations (FANR-Reg-19), undated). When a dwelling or workplace exceeds reference levels, FANR and the responsible person shall develop a risk-based protection strategy or remedial action that optimizes any exposed groups' protection and safety (FANR Regulation 19 for Existing Exposure Situations, Version 0, undated). Article 11 establishes a radon reference level for dwellings and other high-occupancy buildings, and a separate workplace level (Article 11, FANR-Reg-19, undated). Employers are obligated to ensure that activity concentrations in workplaces are as low as possible below the reference level and to optimize protection (Article 12, FANR-Reg-19), undated). When activity concentrations exceed the appropriate reference level, a protection strategy is required to maximize the reduction of radon levels in existing and future buildings per FANR Regulation 24, Standards for Facilities and Activities involving Ionizing Radiation other than in Nuclear Facilities, Version 1, undated. (Article 12, FANR-Reg-19, undated).

3.2 Abu Dhabi Building Codes

3.2.1 Abu Dhabi International Building Code (ADIBC)

Beginning in 2009, Abu Dhabi's DMT adopted new building codes (Abu Dhabi International Building Code (ADIBC), 2013). During construction, ADIBC requires maintenance of AIQ under Abu Dhabi's Environment, Health, and Safety Framework (ADIBC, Section 3302.3).

3.2.2 Abu Dhabi International Mechanical Code (ADIMC)

Applicable to commercial, residential, industrial, and governmental buildings and structures, the Abu Dhabi International Mechanical Code (ADIMC) (2013) impacts air quality by setting minimum standards for the design, installation, and operation of mechanical systems, appliances, appliance venting, duct and ventilation systems, and chimneys and vents. A permit is required when a mechanical system covered by the code is built, installed, enlarged, altered, repaired, removed, or replaced.

a. Building ventilation: To protect occupant health, ADIMC establishes minimum rates of natural ventilation through windows, doors, and openings (ADIMC, Section 402) and prescribes the method and rate of mechanical ventilation, depending on size, capacity, and occupancy use (ADIMC, Sections 403). Ventilation rates vary according to use. For example, public spaces, residences, schools, correctional facilities, hospitals, nursing facilities, convalescent homes, retail stores, sports and amusement facilities, and transportation have specified ventilation rates (see ADIMC, Table 403.3). There are distinct mechanical ventilation requirements for parking garages and adjacent spaces and for uninhabited spaces (ADIMC, Sections 404 and 406). All systems must have manual or automatic controls that operate when the area is occupied (ADIMC, Section 405). A permit is required to repair or upgrade ventilation systems (ADIMC, Section 106).

b. Exhaust: While the focus of the exhaust system requirements in on fire safety and structural integrity, some provisions impact IAQ. ADIMC sets standards for the design, construction, installation, operation and maintenance of mechanical exhaust systems, including exhaust systems serving clothes dryers and domestic kitchen exhaust (Sections 504 and 505); hazardous exhaust systems (Section 510); smoke control systems (Section 513); energy recovery ventilation systems (Section 514); and other specified systems. Exhaust air systems cannot interfere with or be drawn in by ventilation systems (ADIMC, Section 501). These specifications prevent entry of dust, heat, odors, fumes, spray, gas, and smoke that are irritating or injurious to health or safety.

c. Duct systems: To ensure the performance of a building's air distribution system, Chapter 6 of ADIMC prescribes the materials, design, and method of constructing supply, return, and exhaust duct systems for air-conditioning, heating, ventilating, and exhaust. Although the purpose of these provisions is to guarantee fire safety and structural integrity of the mechanical system, the specifications may have the co-benefit of reducing indoor air contamination (See Section 605 – air filter requirements, and 606-smoke detection requirements).

d. Chimneys and vents: ADIMC Chapter 8 regulates the design, construction, installation, maintenance, and repair of chimneys, vents, and their connections to appliances. The specifications prevent the leakage of combustion contaminants (see, for example, Sections 801.18.2 – flue gas passageways and 804.3.1 – direct vent, integral vent, and mechanical draft systems).

Although the ADIBC and ADIMC contain requirements that benefit IAQ, their primary objective is to guarantee structural and mechanical integrity and safety. Realizing that the UAE’s explosive economic and social progress was likely to impact the environment, EAD, DOH, and other UAE and Abu Dhabi government agencies set out to identify environmental health concerns and formulate policy responses.

3.2.3 Estidama's Pearl Rating System

As the UAE was developing its national strategy, DMT created its Pearl Rating System for Estidama (April 2010). As part of creating livable buildings, the Pearl Rating System establishes some mandatory requirements to ensure comfortable IAQ. Estidama's mandatory provisions include:

1. Ventilation delivery: A building's mechanical systems must ensure a minimum delivery of fresh air by separating outdoor air intakes from exhaust points, accurately locating exhaust points, and providing ventilation rates consistent with applicable standards (Estidama, LBi-R1).
2. Legionella prevention: Buildings must manage the risk of Legionnaires' disease by developing and implementing a Legionella management plan for all relevant water-based systems, such as air conditioning, cooling towers, and hot and cold water systems (Estidama, LBi-R3).
3. Ventilation quality: Buildings must provide adequate outdoor ventilation by installing carbon dioxide sensors at each return point and alert systems to ensure that CO_2 levels do not exceed 1000 ppm. Increasing outdoor air ventilation above the ventilation rates in LBi-R1 are encouraged (Estidama, LBi-1).

3.3 Occupational Air Quality

Abu Dhabi Occupational Safety and Health System Framework (OSHAD-SF), Occupational Standards and Guideline Values, Version 3.0 (July 2016) (non-mandatory)

OSHAD established non-mandatory standards and guideline values (referred to as "Threshold Limit Values," or TLVs) for chemical substances in occupational air. TLVs are the maximum allowable limits for occupational exposure to specified chemical substances. The Abu Dhabi Executive Council may change any occupational air threshold limit value to a mandatory standard. Appendix (1) is a list of the TLVs for 794 chemical substances in working areas. The TLVs are considered guidelines that should inform decisions regarding safe levels of exposure to the listed chemical substances found in the workplace. OSHAD's Glossary of Terms, Version 3.1 clarifies the meaning of the Occupational Standards and Guideline Values (Abu Dhabi Occupational Safety and Health System Framework (OSHAD-SF), Glossary of Terms Version 3.1 (March 2019).

Abu Dhabi Occupational Safety and Health System Framework (OSHAD-SF), Technical Guideline, Occupational Air Quality Management, Version 3.1 (Feb. 2019)

OSHAD issued a technical guideline (TG) to help workplace entities determine the objective of an occupational IAQ assessment and provide guidance on how to monitor air quality and collect air samples. The TG lists applicable international standards, guidelines, and methods relevant to sampling and monitoring workplace and IAQ. The TG's incorporation of applicable monitoring and sampling methods, standards, and guidelines ensures consistency, instrument and calibration requirements, indoor and occupational air sampling and monitoring procedures, quality assurance and quality control requirements, and data processing methods. The framework mandates that laboratories used for air quality sampling, monitoring, and measurement be accredited. The TG adopts measurement standards and guidelines for occupational air.

Table 4: Substances listed in the "American conference of governmental industrial hygienists) - ACGIH - 2009 guide to occupational exposure value

Indoor Air	Pollutants / characteristics

1. HVAC system • **Carbon dioxide** • **Ventilation** **2. Thermal comfort** • **Air temperature** • **Relative humidity**	• Asbestos • Carbon monoxide • Formaldehyde • Lead	• Ozone • Particulate matter ($PM_{2.5}$) • Radon • Total volatile organic compounds

- Occupational Air Quality: The differences between occupational air and indoor air necessitate separate monitoring and sampling requirements for occupational and indoor air. The TG identifies potential objectives and approaches to occupational air monitoring. Occupational air sampling methods are listed and discussed in the TG.

- Indoor Air Quality: Acceptable IAQ has air (1) that contains no known contaminants at harmful concentrations, as determined by relevant authorities and (2) to which a substantial majority (80%) of the people exposed do not express dissatisfaction (ASHRAE Standard 62.1- 2007). To guarantee acceptable IAQ, the responsible person must monitor indoor air for contaminants (e.g., volatile organic compounds [VOCs], carbon monoxide), inspect the HVAC system, review the building checklist, and survey occupants' perception of IAQ and health symptoms.

3.4 Standards and Specifications

As per Federal Law No. (28) of 2001, the Emirates Authority for Standardization and Metrology (ESMA) developed the Emirates Conformity Assessment Scheme (ECAS) certification program. The ECAS certificate is proof that the product meets technical requirements for quality and safety and is approved for sale by the UAE federal government. ECAS-certified products with the potential to impact IAQ include detergents, paints, and varnishes.

3.5 Indoor Air Quality (Mandatory)

Facilities Policy Manual, Chapter nine – Health and Safety, DOH Policy for Healthcare Facilities, Occupational and Indoor Air Quality (2010).

DOH requires private and public healthcare facilities to use accredited contractors to monitor occupational and indoor air quality and control exposure to protect human health. The policy outlines a hierarchy of actions to be taken in the event of an exceedance. A risk assessment shall determine the location and frequency of occupational and indoor air quality measurements. However, health care providers must measure IAQ at least annually. DOH issued separate guidance for conducting a risk assessment of chemical hazards in healthcare facilities (Facilities Policy Manual, Chapter nine – Health and Safety, Guidance Note for Healthcare Facilities – Risk Assessment of Occupational and Indoor Air Quality (2010)). The guidance details a four-step risk assessment process to prioritize which substances require further analysis and the control measures needed to ensure public health and safety.

Ambient Air Emissions, Indoor and Occupational Air Quality Management (Standard) (2011)

All nominated healthcare providers licensed by DOH manage occupational and indoor air quality to protect healthcare workers, patients, visitors, contractors, and the public. This standard sets the IAQ objectives for bacteria, yeast, mold, and particle counts. It also incorporates the occupational and indoor air quality requirements outlined in Abu Dhabi's EHSMS Regulatory Framework CoP 1.1. The healthcare providers must conduct an infection-control risk assessment and ensure that the facility has an adequate number of isolation rooms to meet patient demands. In addition to occupational and indoor air quality monitoring, measurement, and risk reduction requirements following approved standard operating procedures, healthcare providers must guarantee the proper installation, monitoring, and maintenance of heating, ventilation, and air conditioning (HVAC) filters. Healthcare providers may contract with accredited service providers to maintain HVAC systems and conduct indoor air quality monitoring. The recordkeeping and reporting requirements ensure enforcement of the standard.

3.6 Indoor Air Quality Policies (Non-mandatory)

National Strategy and Action Plan for Environmental Health United Arab Emirates (2010)

As the UAE's economy and population grew, EAD and the federal government recognized the need to reduce public health impacts of pollution. EAD, in collaboration with DOH and other federal and non-governmental organizations, developed a National Strategy and Action Plan for Environmental Health United Arab Emirates. IAQ was prioritized as an environmental health risk because:

(1) People spend a majority of their time indoors,

(2) Indoor environments have many sources of air pollutants,

(3) Concentrations of indoor air pollutants pose increased health risks, and

(4) Energy-efficient buildings seal buildings, thereby increasing the level of indoor air pollutants (National Strategy, 2010).

The National Strategy established the following targets:

- Reduce pollutant levels and human exposure by (1) evaluating how building codes can improve residential, commercial, and public IAQ, (2) establishing guidelines and regulations for IAQ, (3) assessing the feasibility of inspecting HVAC systems, (4) eventually banning smoking in all public areas, and (5) establishing health units to evaluate and respond to IAQ complaints;

- Improve data quality and availability by (1) conducting a baseline study of the presence of asbestos and asbestos-containing material in commercial, residential, and public buildings, (2) studying IAQ in public buildings and surveying radon across the UAE, (3) tracking diseases associated with indoor air pollution, and (4) setting targets for the number of schools and public buildings with indoor air contaminant levels below international standards for lead, mercury, formaldehyde, asbestos, radon, and mold and reducing the number of residential buildings exceeding radon thresholds;
- Increase understanding of environmental health risks by (1) studying the rate of air exchange in different building typologies, (2) investigating IAQ in green buildings, and (3) assessing indoor air in humid climates;
- Build institutional and human capacity by (1) funding mechanical engineering and indoor air-related programs at local universities, (2) increasing staff at UAE environmental agencies, and (3) auditing staff indoor air expertise;
- Promote urban development that ensures environmental health by incorporating IAQ into building certification programs and measuring the efficacy of such programs;
- Expand environmental awareness by creating standards for and labeling consumer goods that are sources of indoor air pollution, developing and disseminating information on indoor air pollution such as second-hand smoke and radon, and encouraging the installation of carbon monoxide monitors.

Since 2010, EAD, DOH, and other governmental entities have implemented aspects of the National Strategy's targets to improve IAQ. However, there has not been a consistent and integrated approach to achieve the IAQ targets outlined in the National Strategy.

2014 Annual Policy Brief on Enhancing Air Quality in Abu Dhabi

Recognizing that indoor air pollution continues to pose a significant environmental and human health risk to Abu Dhabi residents, DOH and EAD issued an annual policy brief on Enhancing Air Quality in Abu Dhabi (2014). Although the government does not monitor residential IAQ, voluntary actions could reduce indoor air pollution.

The policy brief calls for an improved regulatory framework that sets standards, labels, and guidelines for construction materials that emit pollutants, more heavily regulates smoking in public spaces, and establishes requirements for ventilation and duct cleaning and maintenance.

EAD and DOH also recognized the importance of linking IAQ and public health and maintaining a database of certified building and construction material that satisfies Estidama's requirements (Annual Policy Brief, 2014). Incentives and certification schemes effectively encourage the use of construction materials, cleaning products, services that have a low impact on IAQ.

Continued education and awareness campaigns regarding the human health risks associated with indoor air pollution will further improve IAQ (Annual Policy Brief, 2014). However, coordination among several government agencies and full implementation and enforcement of laws, codes, and initiatives could secure further improvements in IAQ (Annual Policy Brief, 2014).

To enhance IAQ, Abu Dhabi set targets to (1) increase the percentage of new residential buildings that meet Estidama’s standards and (2) reduce emergency room visits for asthma attacks (Annual Policy Brief, Table 7).

3.7 Indoor Air Quality Initiatives

Estidama

In addition to mandatory requirements (that are enforced by Abu Dhabi Municipality, the entity responsible for building permits), Estidama includes several voluntary provisions intended to improve a building or structure's safety and livability. Builders are encouraged to use building materials with little or no impact on IAQ, implement air quality management plans, improve car park ventilation, and improve thermal comfort of occupants.

Materials emissions

- Sealants and adhesives: For all adhesives and sealants used in a building, voluntarily use a minimum of 95% (by weight) that do not exceed the prescribed VOC limits. The VOC limits of the remaining noncompliant adhesives and sealants must be no more than 50% higher than the values listed for each product type. However, 100% of all adhesives and sealants used in schools must be compliant (Estidama, LBi-2.1).
- Paints and coatings: Voluntarily demonstrate that 95% of all surface areas covered by paints and coatings meet or fall below the maximum VOC content limit values for paints and coatings. The VOC limits of the remaining noncompliant paints and coatings must be no more than 50% higher than the values listed for each product type. All paints and coatings must have fungal resistance. One hundred percent of all surface areas covered by paints and coatings in schools must meet the VOC limits prescribed. (Estidama, LBi-2.2).
- Carpet and hard flooring: Voluntarily demonstrate that 100% of all surface areas covered by carpet or hard flooring meet the following requirements (Estidama LBi-2.3):

- Carpets: meet or exceed the Carpet and Rug Institute Green Label or Green Label Plus Program or Green guard Indoor Air Quality Certification Program for Carpets;
- Hard flooring systems and finishes: achieve Floor Score Certification or green guard Indoor Air Quality Certification for low-emitting products, and
- Wood flooring products: do not exceed class E1 for formaldehyde content and do not exceed 5 parts per million (ppm) for pentachlorophenol content. Testing, classifying, and marking wood products is mandated. All remaining non-wood flooring must comply with the requirements above.

- Ceiling systems: Demonstrate that suspended ceiling systems contain no asbestos and meet formaldehyde content requirements (Estidama, LBi-2.4). Non-suspended ceiling systems must comply with the requirements listed in LBi-2.1 for any adhesives and sealants and LBi-2.2 for any paints and coatings. The wood-paneled ceiling must meet the limits and testing requirements for formaldehyde, VOC content, and pentachlorophenol content (Estidama, LBi-2.4).
- Formaldehyde reduction: Voluntarily demonstrate that no internal construction materials or installed furniture exceed formaldehyde VOC content (Estidama, LBi-2.5).
- Indoor air quality management: Voluntarily implement a comprehensive Construction IAQ Management Plan that details construction practices that promote IAQ for building occupants (Estidama, LBi-3).
- Car park quality management: Ensure adequate ventilation of car park areas by demonstrating that the ventilation design meets or exceeds requirements for car parks through continuous measurement of carbon monoxide (CO), nitrogen dioxide (NO_2), and particulate matter (PM10) (Estidama, LBi-4).

Thermal comfort

- Thermal zoning: Voluntarily demonstrate that all spaces within the building(s) are designed with separately controllable thermal zones to achieve occupant comfort (Estidama, LBi-5.1).
    - Private enclosed spaces intended for individual use must have one thermostatic controller to control airspeed or temperature as a minimum.
    - Multi-occupant spaces intended for group activities (meeting rooms, classrooms, lecture theatres, and conference halls) must have at least one thermostatic controller. Spaces with internal partitions to subdivide areas must each have at least one thermostatic controller.
    - Residential spaces must have separate controls for each living area and each bedroom (including maids' rooms). Common areas should follow the requirements relating to inclusive spaces.
    - Schools must have separate zones and controls for each classroom and administrative office.
- Control: Mechanical ventilation and HVAC control requirements must provide individual comfort controls for the well-being, productivity, and thermal comfort of occupants (Estidama, LBi-5.2).

Thermal comfort modeling: Demonstrate through thermal modeling that occupied areas, or living areas and bedrooms for residential spaces, meet fully mechanical ventilation requirements or mixed-mode ventilation (Estidama, LBi-5.3).

Abu Dhabi Trustmark for Environmental Performance

In support of Estidama's Pearl Rating system, Abu Dhabi's Quality and Conformity Council (QCC) also created a voluntary product certification scheme called the Abu Dhabi Trustmark for Environmental Performance (Trustmark). Collaborating with industry, the QCC develops product specifications that comply with international best practice. Trustmark identifies construction materials with low VOC content and no formaldehyde. Since 2013, the QCC has developed certification schemes for:

- Paint
- Adhesives
- Sealants
- Carpets
- Flooring
- Furniture
- Insulation
- Windows
- Door glazing systems
- Gypsum/wallboard

The QCC also certifies electricians and HVAC technicians to ensure that the installation, maintenance, and cleaning activities of mechanical systems do not adversely impact IAQ (under professionals' certifications scheme). Certified bodies use the certification to promote their business.

Part B: Situational and Gap Analysis for Existing or Proposed Institutional Arrangements for IAQ and Health

1. Introduction

The Abu Dhabi Public Health Center (ADPHC) is carrying out an operational review of Abu Dhabi's current indoor air quality (IAQ) capabilities. For the purposes of this project, IAQ is defined as the totality of indoor air characteristics that influence the health and well-being of an individual. This project addresses IAQ in residential settings; public spaces such as school, government, retail, and corporate buildings; and workplace settings such as offices and other public, government, or corporate buildings where people work. This project does not address occupational exposure to hazardous airborne chemical substances in industrial, agricultural, or construction settings.

Understanding IAQ and controlling indoor air pollutants is important to protect public health. Construction materials, tobacco products, cleaning equipment, ventilation systems, moisture, and outside sources such as radon or pesticides are sources of indoor air pollutants. When ventilation inside a building is inadequate, these pollutants can build up in indoor air to levels that can have immediate or long-term health implications.

The aim of this chapter of the project was to conduct a Situational and Gap Analysis for Existing or Proposed Institutional Arrangements for IAQ and Health

2. Approach

This situational and institutional gap analysis builds off the following:

a. Stakeholder surveys provided inputs into existing institutional arrangements, research, monitoring, and general awareness of IAQ in Abu Dhabi Emirate (chapter 2 part B).

b. Review of Existing Local Governance Structures, Policies and Regulations, Guidelines, Strategies, and Activities Related to IAQ and Health (chapter 2, part A)
c. Situational and Gap Analysis for Existing or Proposed Testing and Monitoring Standards or Guidelines for IAQ in Abu Dhabi Emirate (chapter 3).
d. Baseline Parameters and Health-Based Indicators and Targets for IAQ (chapter 4, part A) and Review of the Scientific Evidence Base on the Link between IAQ and Health (chapter 4, part B).

3. Findings

3.1 Stakeholder Survey

Stakeholder mapping was performed on both federal and local levels. Potential participants who had a role in governing, regulating, or executing environmental health-related activities were identified. These potential partners were approached via official letter (appendix 2) and requested to nominate representatives for their entities. Twenty-seven entities were identified and approached. Twenty-five entities responded with 44 representatives (as some entities nominated more than one individual), and two entities remained nonresponsive.

One-to-one interviews were initially planned for each entity; however, due to the pandemic, the survey was sent electronically to participating nominees. Participant input was considered as subject matter expert feedback rather than as individual entity feedback (as some entities had more than one nominee. Two sets of questions were prepared, one for academic entities and another for the rest. The questionnaire covered the following domains:

1. Introductory questions
2. Research capacities related to indoor air quality and public health
3. Testing and monitoring of indoor air quality
4. Operational capacities related to indoor air quality and public health

5. Governance, policies and regulations related to indoor air quality and public health

The questionnaire included 25 questions, with more sets of sub-questions (almost 50 in total). It was designed to include mainly open-ended questions in order to capture the maximum possible information. The capacity of each open-ended question field was 800 words. Closed-ended questions, rating questions, and Likert scale questions were included as well.

Responses then were transferred into a spread sheet, categorized, and analyzed.

Stakeholder surveys provided information on IAQ-related institutional arrangements, local governance systems, testing and monitoring, data collection, and study and health conditions in the Emirate of Abu Dhabi. Representatives of local and federal government agencies and academic organizations were among the surveyed entities.

Table 5: List of surveyed entities

No.	Classification	Entity
1.	Academia (6 entities)	• United Arab Emirates University • Sorbonne University Abu Dhabi • Zayed University • Abu Dhabi University • Khalifa University • New York University Abu Dhabi
2.	Federal Government (6 entities)	• Ministry of Health and Prevention • United Arab Emirates Ministry of Climate Change and Environment • Ministry of Education • Ministry of Economy • Emirates Authority of Standardization and Metrology • Federal Authority for Nuclear Regulation
3.	Local Government (10 entities)	• Abu Dhabi Quality and Conformity Council • Abu Dhabi Agriculture and Food Safety Authority • Department of Municipalities and Transport • Department of Education and Knowledge • Environmental Agency – Abu Dhabi • Department of Culture and Tourism

		• General Authority of Islamic Affairs and Endowments • Department of Health – Abu Dhabi • Abu Dhabi Housing Authority • Department of Energy
4.	Others (4 entities)	• Abu Dhabi Health Services Co. • Mubadala • Emirates Medical Association • ZonesCorp

Survey Questions

For Academia

Introductory Questions

1. What are your greatest concerns related to health effects associated with indoor air quality in Abu Dhabi Emirate?
2. In your view, what pollutants are of specific concern for non-occupational IAQ in the Abu Dhabi Emirate?
   a. What are their sources?
   b. Please rate/prioritize the need for attention for each pollutant using the following phrases: immediate (<2 years), mid-term (3-5 years), and long-term (5-10 years)?

Research Capacities Related to Indoor Air Quality and Public Health

3. What is your organization's role in indoor air quality research?
   a. Please describe your capacity for indoor air quality research, including types of expertise on staff, laboratory and analytical capabilities, partnerships with other entities, etc.
   b. Please give examples of indoor air quality research projects that your organization has been involved with in the past 5 years.
   c. Do you undertake research into monitoring indoor air quality?

d. What is your funding mechanism for indoor air quality research?

e. Who or what sets the research agenda for indoor air quality within your entity or outside?

4. What barriers do you face in doing indoor air quality research in Abu Dhabi? How do you think these barriers could be overcome?

5. What research questions do you believe need to be answered on indoor air pollution?

   a. Are there questions about specific contaminants, sources of contaminants, exposures, etc.?

   b. Which agencies or organizations do you believe are best equipped to research these questions?

Testing and Monitoring of Indoor Air Quality

6. Is IAQ testing or measurement currently being performed at residences? Please describe the measurement technique(s).

7. In your opinion, who should test and monitor IAQ? *(For example: product manufacturers, homebuilders, rental property owners, government agencies, residents.)*

8. In your opinion, who should pay to test and monitor IAQ? *(For example: product manufacturers, homebuilders, rental property owners, government agencies, residents.)*

9. Do you think Abu Dhabi residents would allow IAQ sensors to be installed in their residences to report IAQ data to the government?

10. Do you think Abu Dhabi residents would allow a government representative inside their residences to collect IAQ measurements?

11. Should minimum performance specifications be required for any IAQ sensor or measurement method? If so, what do you think are the most important specifications?

12. In your opinion, what is the desired frequency of measurement (e.g., yearly, quarterly, or daily) and time resolution (e.g., continuous, grab sample measurements, or integrated measurements such as filters or cartridges) of indoor air quality monitoring?

Operational Capacities related to Indoor Air Quality and Public Health

13. What operational actions or decisions around indoor air quality are undertaken by your organization? Please tell us about some specific examples to help illustrate your operational role.

    a. Are there any actions or decisions under your organization's authority that you are enforcing to other entities? What are they and how are you ensuring compliance?

    b. Are there any actions or decisions that are currently not under your organization's authority that you think should be?

    c. What types of expertise exist in your organization to support these activities?

    d. What are the biggest operational barriers your organization is facing?

    e. How do you think these barriers could be overcome?

14. Does your organization have the capacity (people with necessary knowledge, equipment) to monitor IAQ over the long term?

15. Do you see any indoor air quality operational gaps across the Emirate?

16. Are there any gaps in indoor air quality expertise within your organization?

17. Do you see any larger gaps in indoor air quality expertise across agencies across the Emirate?

18. Is your organization collecting data related to adverse health outcomes due to indoor air quality?

    a. What are the types of data you collect?

    b. How does your agency use the data?

    c. For what health outcomes do you collect data?

    d. How do you connect health data to specific contaminant exposures (if at all)?

    e. How data are archived and made available for use?

    f. Are there other data that would be useful for your organization to have?

    g. Is there an opportunity to better manage health data?

19. Does your organization coordinate and/or share data with any other entity? If so, under what circumstances?

Governance, Policies and Regulations Related to Indoor Air Quality and Public Health

20. What agencies in Abu Dhabi Emirate are responsible and/or have the legal mandate for creating, implementing and enforcing laws, policies, regulations, and standards around indoor air quality and public health?

21. What roles and responsibilities does your organization have related to indoor air quality governance?

    a. What are the laws, policies and regulations your organization is following or has issued and how are they enforced?

    b. Are there legal structures in place to support your role?

c. Which other agencies or organizations do you work with on governance matters? What mechanisms or procedures are in place to enable inter-agency coordination?

22. What IAQ policies are currently in place for residences and other non-occupational buildings? If so, for what pollutant(s)?

23. For new commercial products used in residences, are there policies in place to ensure that emissions of certain pollutants are within limits (for example, VOC emissions from new furniture) before they are sold/put on the market?

24. What is the biggest barrier to the implementation of IAQ regulations and policies in Abu Dhabi Emirate?

25. What other barriers is your organization facing related to indoor air quality governance? How do you think these barriers could be overcome?

For Government

Introductory Questions

1. What are your greatest concerns related to health effects associated with indoor air quality in Abu Dhabi Emirate?

2. In your view, what pollutants are of specific concern for non-occupational IAQ in the Abu Dhabi Emirate?

    a. What are their sources?

    b. Please rate/prioritize the need for attention for each pollutant using the following phrases: immediate (<2 years), mid-term (3-5 years), and long-term (5-10 years)?

Governance, Policies and Regulations Related to Indoor Air Quality and Public Health

3. What agencies in Abu Dhabi Emirate are responsible and/or have the legal mandate for creating, implementing and enforcing laws, policies, regulations, and standards around indoor air quality and public health?
4. What roles and responsibilities does your organization have related to indoor air quality governance?
   a. What are the laws, policies and regulations your organization is following or has issued and how are they enforced?
   b. Are there legal structures in place to support your role?
   c. Which other agencies or organizations do you work with on governance matters? What mechanisms or procedures are in place to enable inter-agency coordination?
5. What IAQ policies are currently in place for residences and other non-occupational buildings? If so, for what pollutant(s)?
6. For new commercial products used in residences, are there policies in place to ensure that emissions of certain pollutants are within limits (for example, VOC emissions from new furniture) before they are sold/put on the market?
7. What is the biggest barrier to the implementation of IAQ regulations and policies in Abu Dhabi Emirate?
8. What other barriers is your organization facing related to indoor air quality governance? How do you think these barriers could be overcome?

Operational Capacities Related to Indoor Air Quality and Public Health

9. What operational actions or decisions around indoor air quality are undertaken by your organization? Please tell us about some specific examples to help illustrate your operational role.
    a. Are there any actions or decisions under your organization's authority that you are enforcing to other entities? What are they and how are you ensuring compliance?
    b. Are there any actions or decisions that are currently not under your organization's authority that you think should be?
    c. What types of expertise exist in your organization to support these activities?
    d. What are the biggest operational barriers your organization is facing?
    e. How do you think these barriers could be overcome?
10. Does your organization have the capacity (people with necessary knowledge, equipment) to monitor IAQ over the long term?
11. Do you see any indoor air quality operational gaps across the Emirate?
12. Are there any gaps in indoor air quality expertise within your organization?
13. Do you see any larger gaps in indoor air quality expertise across agencies within the Emirate?
14. Is your organization collecting data related to adverse health outcomes due to indoor air quality?
    a. What are the types of data you collect?
    b. How does your agency use the data?
    c. For what health outcomes do you collect data?
    d. How do you connect health data to specific contaminant exposures (if at all)?

e. How data are archived and made available for use?

f. Are there other data that would be useful for your organization to have?

g. Is there an opportunity to better manage health data?

15. Does your organization coordinate and/or share data with any other entity? If so, under what circumstances?

Research Capacities Related to Indoor Air Quality and Public Health

16. What is your organization's role in indoor air quality research?

    a. Please describe your capacity for indoor air quality research, including types of expertise on staff, laboratory and analytical capabilities, partnerships with other entities, etc.

    b. Please give examples of indoor air quality research projects that your organization has been involved with in the past 5 years.

    c. Do you undertake research into monitoring indoor air quality?

    d. What is your funding mechanism for indoor air quality research?

    e. Who or what sets the research agenda for indoor air quality within your entity or outside?

17. What barriers do you face in doing indoor air quality research in Abu Dhabi? How do you think these barriers could be overcome?

18. What research questions do you believe need to be answered on indoor air pollution?

    a. Are there questions about specific contaminants, sources of contaminants, exposures, etc.?

b. Which agencies or organizations do you believe are best equipped to research these questions?

Testing and Monitoring of Indoor Air Quality

19. Is IAQ testing or measurement currently being performed at residences? Please describe the measurement technique(s).

20. In your opinion, who should test and monitor IAQ? *(For example: product manufacturers, homebuilders, rental property owners, government agencies, residents.)*

21. In your opinion, who should pay to test and monitor IAQ? *(For example: product manufacturers, homebuilders, rental property owners, government agencies, residents.)*

22. Do you think Abu Dhabi residents would allow IAQ sensors to be installed in their residences to report IAQ data to the government?

23. Do you think Abu Dhabi residents would allow a government representative inside their residences to collect IAQ measurements?

24. Should minimum performance specifications be required for any IAQ sensor or measurement method? If so, what do you think are the most important specifications?

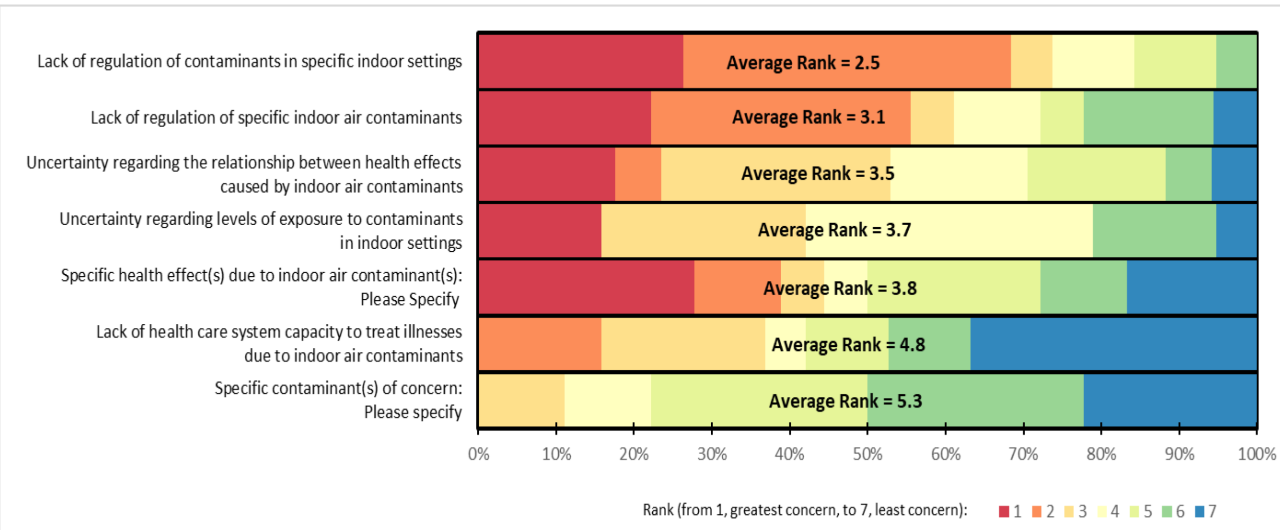
25. In your opinion, what is the desired frequency of measurement (e.g., yearly, quarterly, or daily) and time resolution (e.g., continuous, grab sample measurements, or integrated measurements such as filters or cartridges) of indoor air quality monitoring?

3.1.1 Highlights of Survey Results

- Pollutants of Concern. The most selected pollutants of concern were particulate matter (22 respondents), carbon monoxide (19 respondents), and mold (17 respondents). Fewer respondents (11–14) identified incense combustion products (14 respondents), nitrogen dioxide (12 respondents), tobacco smoke (12 respondents), and formaldehyde (11 respondents).

- Issues of Concern. The issues of greatest concern among respondents relate to lack of regulation of both specific indoor settings and of specific indoor air contaminants, with more than half ranking these first or second (Figure 1). Uncertainties regarding health effects caused by indoor air pollutants and levels of exposure to contaminants in indoor settings were of middling concern and were ranked 3rd or 4th by about half of respondents.

Figure 1: Percentage of respondents ranking specific IAQ-related issues from those of most concern (rank=1) to those of least concern (rank=7)

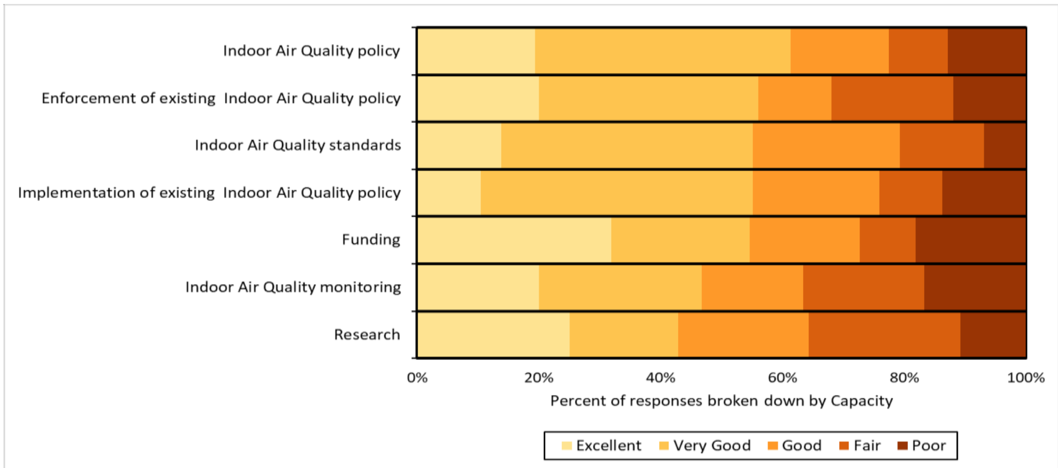


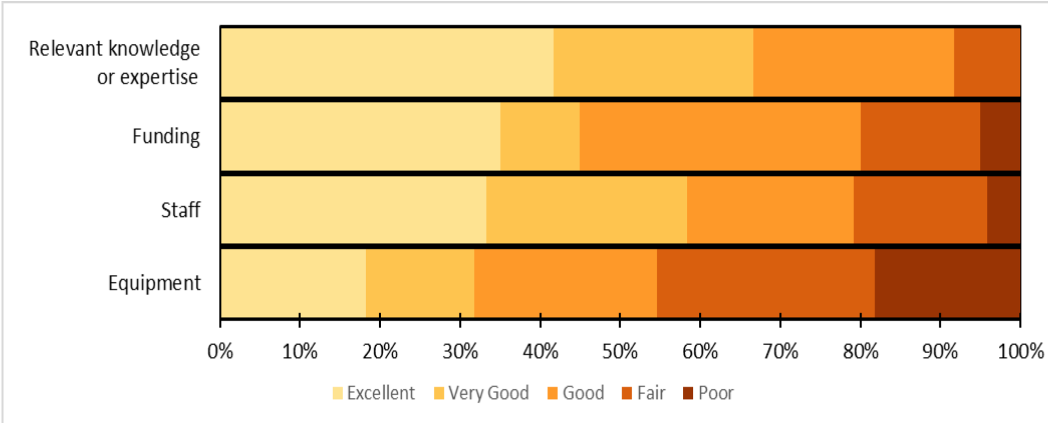
- Capacity to Regulate. Although lack of regulation was the most cited issue with IAQ, most respondents rated Abu Dhabi's capacity to regulate and monitor IAQ as good, very good, or excellent (Figure 2, top). When asked about capacity to implement particular roles and responsibilities related to IAQ, most respondents rated knowledge, staff, and funding as excellent or very good, but when asked about equipment, they rated that capacity lower, with as many rating it poor as excellent (Figure 2, bottom). Thus, it seems likely that the entities have the knowledge, staff, and even funding to increase activity regulating IAQ, but need to invest in additional equipment.

- Understanding of Policies and Legal Structures. Respondents' understanding and awareness of various IAQ policies and regulations varied widely, as did the policies their organizations issued, followed, or enforced. The most mentioned policy of which respondents were aware, and their organization follows, was ADPHC / OSHAD's guidelines on managing IAQ in occupational situations. Only about half of respondents knew of legal structures in place to support their roles; the rest either did not know or said there were none (but this last response was not common). These findings suggest a need to educate organizations about the legal structures in place to regulate IAQ.

- Data Sharing. Eight respondents answered that the organization they represent collects data related to indoor air pollutants and their health effects; however, only one of those makes the data available. This suggests a need for outreach and interagency agreements and collaboration; data cannot be used to protect human health if the collectors do not share it.

Figure 2: Rating of capacity to regulate (top) and implement roles and responsibilities (bottom) related to IAQ





3.1.2 Barriers to IAQ Regulation, Policy, and Implementation

A. Barriers to Setting IAQ Regulations and Policies

Obstacles noted by respondents from academia were insufficient study and the lack of a single responsible agency to take the lead on IAQ. One professor pointed to the lack of research performed locally in the Emirate of Abu Dhabi. Later in the survey, this professor emphasized the need for awarding dedicated research grants to local universities in Abu Dhabi Emirate (as opposed to “big university names that will just come for the project and won’t be held accountable if their estimate turns out to be inaccurate years later.”) Another professor observed that the Emirate could convene stakeholder meetings to identify and agree on a single responsible agency to take the lead on IAQ.

Respondents in the Emirate government identified insufficient research, lack of public awareness, and lack of enforcement and unified commitment from leadership as barriers. Evidence for inadequate study provided by these respondents included improper recognition of the causes of IAQ deficiency in Abu Dhabi and a lack of data to assess the correlation between IAQ standards and health outcomes.

One respondent pointed to the lack of experts and commitment as one reason for insufficient IAQ research in the Emirate. Those who noted a lack of public awareness suggested that public health agencies target awareness campaigns to residential companies and building owners.

Those who noted a lack of enforcement and unified commitment from Emirate or federal leadership suggested overcoming that barrier through audits of policy and standards implementation and stricter punitive actions for noncompliance found in those audits. Two Emirate government employees believed no such barriers to setting regulations and policies exist.

Respondents in the federal government identified insufficient research and lack of enforcement and unified commitment from leadership as barriers. Federal government employees that noted insufficient research indicated a need for more studies on the health impact of IAQ. Those who identified a lack of unified commitment pointed to the variety of local and federal agencies tasked with IAQ. The respondents further elaborated that federal IAQ legislation should be passed and that local governments at the Emirate level should be authorized to enforce the implementation of the policies and regulations.

B. Barriers to Implementing IAQ Regulations and Policies.

Respondents in academia identified lack of public awareness and lack of funding and training for monitoring IAQ as barriers. One respondent believed that increasing environmental education would improve awareness of IAQ issues, which could then lead to higher uptake of IAQ regulations and policies.

Two respondents noted that testing and monitoring protocols could be improved to increase implementation. They asked to establish monitoring protocols that would be administered by “qualified individuals” with “proper equipment.” For this to happen, they noted, more funding for monitoring training would also be required.

Respondents in the Emirate government identified lack of enforcement, lack of funding and training for monitoring IAQ, and lack of institutional or organizational knowledge and leadership as barriers. Five Emirate government employees noted the lack of enforcement as a major barrier to implementation. As two of these respondents observed, even if policies and regulations exist, there is no supervision or auditing to ensure proper implementation of policies and regulations or to capture noncompliance. One respondent suggested that IAQ tests be mandated and that a reporting mechanism be developed for noncompliance or incidents. Another respondent suggested administering fines for noncompliance.

Finally, one respondent suggested that IAQ monitoring can be implemented widely by enforcing one agency in each municipality to conduct IAQ tests for all buildings throughout that municipality. Respondents that identified the lack of funding and training of IAQ monitoring specialists as a barrier asked for training programs through the Abu Dhabi Quality and Conformity Council (QCC).

The two respondents that noted a lack of institutional or organizational knowledge and leadership specifically pointed to a “lack of understanding of the stakeholders’ roles” in negatively affecting uptake of IAQ policies and regulations and the need for a “clear identification of roles and responsibilities for each entity.”

Respondents in the federal government identified lack of enforcement, lack of institutional or organizational knowledge and leadership, and lack of public awareness as barriers. Three federal employees asked for more federal regulations, better coordination between relevant entities, and continuous monitoring. As one respondent said, “If there is a regulation, I don’t think that implementing it will cause any problem in future projects. Problems might be faced with old houses and facilities,” indicating that the majority of pushback comes from retroactive implementation of IAQ policies and regulations in existing residences and buildings.

Another barrier identified by federal employees was the lack of institutional or organizational knowledge and leadership. The same respondent who identified a lack of unified commitment as a major barrier in setting IAQ policies and regulations emphasized that unified leadership at the national level would be required to pass federal IAQ legislation, which would authorize local governments at the Emirate level to enforce the implementation of the policies and regulations.

A second respondent shared that they had noticed a "lack of vision and mutual cooperation" from leadership. Finally, a respondent noted once again that one barrier to implementation was the lack of available information and data for relevant stakeholders.

4. Overview of Possible Recommendations

Based on the situational and gap analysis for existing or proposed institutional arrangements for IAQ and health in Abu Dhabi Emirate, there appear to be three primary categories of recommendations: governance, monitoring and research, and public awareness and education.

4.1 Governance

Structure

- Set clearly articulated roles and responsibilities for compliance and enforcement of IAQ standards. Define different stakeholders' roles and responsibilities.
- Create a cohesive IAQ regulatory program responsible for setting standards, certifications, requirements, and methods of compliance assurance.
- Update and revisit how existing standards are enforced and monitored. Specify which agencies or officials will monitor compliance with existing or new standards, and how noncompliance will be corrected.

- Specify which parties (e.g., building owners, residents, or public officials) are responsible for complying with IAQ standards. Details would include the frequency with which measurements should be taken, where measurements should be reported or published, which party bears costs for monitoring, and the incentives for compliance or consequences for noncompliance.
- Establish a professional body for the Emirate to assist with guideline values for indoor air pollutants, ventilation systems, and household products that emit pollutants.

Standards

- Set mandatory minimum levels for pollutants and other components of IAQ that buildings are legally required to meet.
- Recommend higher standards that are suggested but not required, and provide incentives for builders who meet them, perhaps as part of Estidama certification.
- To the extent possible, apply IAQ requirements to all non-occupational buildings and structures, including residential villas. In individual residences, policies should generally be recommended rather than required.
- Prioritize regulating $PM_{2.5}$, PM_{10}, ETS, incense, natural cooking gas, formaldehyde, benzene, radon, and mold.
- Set standards for indoor temperature, humidity, ventilation, air exchange rates, HVAC maintenance, and other non-pollutant factors that impact indoor air by bringing in fresh air or influencing conditions in which pollutants like mold occur.
- Consider expanding the IAQ elements of Estidama's voluntary certification and expanding incentives for building owners to seek certification.

Other Regulations

- Develop guidance for testing indoor air for pollutants.
- Develop certification guidelines for all household products sold in Abu Dhabi to be of low-emission materials, including imported and domestically produced products.
- Require CO monitors in the kitchen of any residence with natural gas cooking.

4.2 Monitoring and Research

Data Collection and Monitoring

- Establish an Abu Dhabi environmental surveying program to take periodic survey measurements of IAQ.
- Track the prevalence of indoor smoking in homes and other buildings to assess baseline levels and improvements.
- Develop additional data on $PM_{2.5}$ to characterize indoor air, quantify risks associated with poor IAQ, and link IAQ experienced in Abu Dhabi with environmental health impacts.
- Update indoor air pollutant exposure measurements in residences and other settings, such as schools. Measurements of major indoor air contaminants, including but not limited to $PM_{2.5}$, PM_{10}, radon, formaldehyde, benzene, and CO, as well as assessments of the prevalence of mold, environmental tobacco smoke, natural cooking gas, and incense burning frequency, are necessary to understand the health risks associated with IAQ.

Research and Expertise

- Focus research specifically on IAQ issues associated with green buildings in hot climates; the tight sealing of these buildings to promote energy efficiency also can lead to IAQ problems.
- Quantify the economic benefits of healthy indoor air.
- Establish and continually update an IAQ research agenda.
- Publish or publicly share de-identified data on IAQ issues to the greatest extent possible, to facilitate research.
- Improve collaboration between agencies and academia.
- Develop technical guidance documents for collecting IAQ measurements and conducting risk assessments to ensure that measurements and risk assessments are being conducted in a standardized way across different residences.

4.3 Public Awareness and Education

- Conduct public health information campaigns on the health risks of poor IAQ and the behaviors that impact indoor air. Particularly relevant topics for Abu Dhabi would include campaigns on the risks of exposure to secondhand smoke from tobacco products (including shishas) and to incense burned indoors without proper ventilation.
- Campaigns could also promote using fans and vents while cooking and installing sensors and monitors for smoke, CO, $PM_{2.5}$, and other pollutants.

- Establish a program to educate building owners on IAQ standards and enforcement, aiming to make them aware of their responsibilities for testing, monitoring, and improving IAQ in their buildings.
- Educate residents on IAQ standards, including which government entities they can contact to report IAQ issues or concerns.

Chapter 3: Situational and Gap Analysis for Existing Testing and Monitoring Standards or Guidelines for IAQ in Residential and Public Buildings

1. Introduction

The Abu Dhabi Public Health Center (ADPHC) is carrying out an operational review of Abu Dhabi's current indoor air quality capabilities (IAQ). For the purposes of this project, IAQ is defined as the totality of indoor air characteristics that influence the health and well-being of an individual. This project addresses IAQ in residential settings; public spaces such as school, government, retail, and corporate buildings; and workplace settings such as offices and other public, government, or corporate buildings where people work. This project does not address occupational exposure to hazardous airborne chemical substances in industrial, agricultural, or construction settings.

Understanding IAQ and controlling indoor air pollutants is important to protect public health. Construction materials, tobacco products, cleaning equipment, ventilation systems, moisture and outside sources such as radon or pesticides are sources of indoor air pollutants. When ventilation inside a building is inadequate, these pollutants can build up in indoor air to levels that can have immediate or long-term health implications.

This chapter of the project aims at conducting Situational and Gap Analysis for Existing Testing and Monitoring Standards or Guidelines for IAQ in Residential and Public Buildings

2. Approach

The monitoring standards for key priority pollutants determined through literature review were reviewed. The approach included reviewing existing monitoring standards in Abu Dhabi with the focus on indoor air pollutants. It was found through this review that most regulations for IAQ were interlinked with building ventilation standards. Hence, the focus was diverted to standards for specific pollutants, as well as for other parameters such as temperature, relative humidity, and ventilation (or air exchange) rates.

3. Findings

3.1 Priority Pollutants of Interest

Based on a detailed review of the baseline conditions in the Emirates and based on stakeholder feedback and responses, the following list of pollutants are considered high priority:

- $PM_{2.5}$
- PM_{10}
- Radon
- Formaldehyde (HCHO)
- Benzene
- Environmental tobacco smoke (ETS)
- Incense combustion products
- Mold
- Nitrogen dioxide (NO_2)

Although ETS and incense combustion products are sources that emit multiple pollutants, including particulate matter (PM), formaldehyde, other volatile organic compounds (VOCs), and carbon monoxide (CO), they are explicitly identified in the list of priority pollutants to demonstrate their importance.

NO_2 is also recommended as an additional priority pollutant based on recent evidence in the literature that links it with childhood asthma. Other common indoor air pollutants in Abu Dhabi that are reported in the literature include CO, carbon dioxide (CO_2), ozone (O_3), sulfur dioxide (SO_2), asbestos, hydrogen sulfide (H_2S), and other bioaerosols. However, their prevalence in indoor conditions in Abu Dhabi is most often lower than recommended levels, and therefore, they are not considered priority pollutants for this review.

3.2 Indoor Air Pollution Sources

Typical sources that influence IAQ in Abu Dhabi include smoking; use of incense, home solvents, wall paints, adhesives, and building and furniture construction materials; cooking; and infiltration into residences of outdoor air pollutants produced by vehicles, industries, and dust storms.[15,16,17,18] In addition, radon, a naturally occurring gas from soil and rocks, infiltrates through openings / gaps in floors and walls.

In the stakeholder survey, respondents mentioned poorly maintained heating, ventilation, and air conditioning (HVAC) equipment as a source, and noted that more than 50% of the buildings are environmentally controlled with HVAC systems. Most respondents said that the HVAC systems contained just particle filters or that they did not know the filter system used.

3.3 Existing UAE and Abu Dhabi Testing and Monitoring Standards

IAQ in residences is not regulated by government entities on a regular basis due to privacy issues. Existing efforts to improve IAQ are based on voluntary actions.[16] Abu Dhabi has the following legal framework for managing IAQ including Federal Law No. 24 of 1999 (articles 55 to 57); the Federal Cabinet Ministers Decree No. 12 of 2006 (articles 12 and 13); the Federal Law No. (15) of 2009; the Ministerial Decree No. (42) of 2008; the Federal Cabinet of Ministers Decree No. (39) of 2006; the Department of Municipalities and Transport (DMT), Estidama Pearl Rating System requirements; and the Department of Health – Abu Dhabi Occupational Safety and Health System Framework.

The Environment Agency – Abu Dhabi (EAD) commissioned the National Strategy and Action Plan for Environmental Health in 2010 to address IAQ, but it was never formally implemented. There are regulations on pollution sources such as construction materials and building contents available in the market, and maintenance requirements for ventilation systems.

Mandatory regulations that govern IAQ are related to smoking, asbestos, and minimum ventilation rates in buildings. The Federal Ministry of Climate Change and Environment (MoCCAE) establishes smoke-free zones outside of air intakes and windows, and requires that the perimeters of residential units be sealed and that weather stripping be applied on internal doors leading to common areas to prevent leakage of tobacco smoke from indoors.

No information is available on how this is monitored and evaluated over time. Similar to MoCCAE, the Estidama Pearl Rating System also establishes smoke-free zones outside of air intakes and windows, and requires sealing of residential unit perimeters and use of weather stripping.

In addition, DMT bans use of asbestos in new buildings and requires building permits for renovation of existing buildings. It requires owners to have residential apartments surveyed by a licensed asbestos consultant to determine whether asbestos or asbestos-containing materials are present. Section 403 of the Abu Dhabi International Mechanical Code establishes minimum rates of natural ventilation and mechanical ventilation. Section 605 specifies air filter requirements and Section 606 specifies smoke detection requirements.

The Abu Dhabi Quality and Conformity Council (QCC) has developed a product certification scheme called the Abu Dhabi Trustmark for Environmental Performance (https://qcc.gov.ae/Trustmark), which issues certification to manufacturers who meet QCC requirements. This scheme covers areas such as energy efficiency and reduction of carbon emissions and toxic materials.

The Emirates Authority for Standardization and Metrology (ESMA) certifies products sold in the UAE, including paints, varnishes, and detergents; ESMA also issues other standards related to IAQ. Abu Dhabi's Department of Culture and Tourism (DCT) follows American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standards for air quality.

DMT has established mandatory measures to improve ventilation. In addition, as part of its green buildings initiative (the Estidama Pearl Rating System), DMT has established incentives to encourage the voluntary use of low-emission materials. Relevant credits and standards within the

Estidama Pearl Building Rating System and the Estidama Pearl Villa Rating System include the following:[19]

- Healthy Ventilation Delivery (Estidama Pearl Building Rating System, LBi-R1, mandatory credit): To protect the quality of air drawn into buildings for ventilation and to ensure minimum delivery of outdoor fresh air, this mandatory credit requires the following:
  - Conduct an observational survey of local air quality according to Sections 4.2 and 4.3 of ASHRAE 62.1.2007;
  - Ensure compliance with separation distances between outdoor air intakes and any exhausts or discharge points according to ASHRAE 62.1.2007;
  - Locate all exhausts outside of the defined public realm; and
  - Demonstrate that all occupied areas in the building comply with the minimum thresholds set out in ASHRAE 62.1:2007 using the ventilation rate procedure.
- Minimum Ventilation (Estidama Pearl Villa Rating System, LV-R3, mandatory credit): To ensure minimum delivery of outdoor fresh air, demonstrate that the villa has been designed to comply with all ventilation requirements set out in the Abu Dhabi International Mechanical Code, Chapter 4.
- Ventilation Quality (Estidama Pearl Villa Rating System, LBi-1, optional credit): Specifies the use of permanent CO_2 monitoring and alert systems to maintain CO_2 below 1000 ppm. The ventilation rate assessment procedure is based on ASHRAE 62.1.2007. This credit is not applicable to residential buildings.
- Improved Ventilation (Estidama Pearl Villa Rating System, LV-2): To protect the quality of air drawn into the villa for ventilation and to ensure minimum delivery of outdoor fresh air, this optional credit allows for both a 15% increase in mechanical ventilation minimum outdoor air ventilation rates established in LV-R3 and a 25% increase in the openable window areas used for natural ventilation established in LV-R3.

- Material Emissions
  - Sealants and adhesives (Estidama Pearl Building Rating System, LBi-2.1, optional credit): For all adhesives and sealants used in a building, voluntarily use a minimum of 95% (by weight) that are below the prescribed VOC limits in Rule 1168 of the South Coast Air Quality Management District6 (SCAQMD) in California. The limits vary from 50 g/L for carpet adhesive to 100 g/L for wood flooring adhesive to 250 g/L for architectural sealants. Some of the limits in the SCAQMD rule 1168 are further reduced effective January 1, 2023 (e.g., wood flooring adhesive from 100 to 20 g/L). The VOC limits of the remaining noncompliant adhesives and sealants must be no more than 50% higher than the SCAQMD values listed for each product type. However, 100% of all adhesives and sealants used in schools must be compliant.
  - Paints and coatings (Estidama Pearl Building Rating System, LBi-2.2, optional credit): Voluntarily demonstrate that 95% of all surface areas covered by paints and coatings meet or fall below the maximum VOC content limit values for paints and coatings specified in Annex II, Phase II of European Directive 2004/42/CE:2004.7 The limits range from 30 g/L for interior matte walls and ceilings to 100 g/L for glossy walls, ceilings, and multicolored coatings; 700 g/L for wood stains; and 750 g/L for binding primers. The VOC limits of the remaining noncompliant paints and coatings must be no more than 50% higher than the values listed above for each product type. All paints and coatings must have fungal resistance. School projects that pursue this credit must demonstrate that 100% of all surface areas covered by paints and coatings have VOC limits no more than the limits prescribed per Annex II, Phase II of European Directive 2004/42/CE: 2004.

- Carpet and hard-flooring (Estidama Pearl Building Rating System, LBi-2.3, optional credit): Voluntarily demonstrate that 100% of all surface areas covered by carpets and hard flooring comply with the Carpet and Rug Institute Green Label, or Green Label Plus Program, or Green guard Indoor Air Quality Certification Program for Carpets and Floor Score Certification, or Green guard Indoor Air Quality Certification for low-emitting products. Wood flooring products should not exceed class E1 for formaldehyde content (<0.1 ppm) and 5 ppm for pentachlorophenol content. Testing, classifying, and marking wood products is mandated. All remaining non-wood flooring must comply with the requirements above.
- Ceiling systems (Estidama Pearl Building Rating System, LBi-2.4, optional credit): Demonstrate that suspended ceiling systems contain no asbestos and meet formaldehyde content requirements (< 0.1 ppm). Non-suspended ceiling systems must comply with the requirements listed in LBi-2.1 for any adhesives and sealants and LBi-2.2 for any paints and coatings. Wood-paneled ceilings must meet the limits and testing requirements for formaldehyde, VOC content, and pentachlorophenol content.
- Formaldehyde reduction (Estidama Pearl Building Rating System, LBi-2.5, optional credit): Voluntarily demonstrate that all internal construction materials and installed furniture emit less than 0.1 ppm of formaldehyde (class E1 level).
- General material emissions (Estidama Pearl Villa Rating System, LV-6, optional credit): Voluntarily demonstrate that all adhesives, sealants, paints and coatings meet the requirements detailed above. Similarly, voluntarily demonstrate that all carpet, hard flooring and ceiling systems and all materials/products containing formaldehyde meet the requirements detailed above.

Other sections of the Estidama Pearl Rating System document provide guidance on thermal comfort controls, lighting, daylight and glare, views, and indoor noise pollution. Estidama LBi-5.1 and 5.2 specify designing cooling zones based on the area of the space—a maximum of 35 m^2 of open space along the building perimeter and a maximum of 75 m^2 open space in internal areas. It also specifies separate controls for each living area and each bedroom in residences.

Few respondents to the stakeholder survey knew if IAQ testing is performed in residences, and none responded to the survey question related to types of measurement techniques used in residences. Most of the respondents noted that Abu Dhabi residents would be open to installation of sensors in their residences and to having the data reported to the government.

3.4 Measurement Methods

This section summarizes standard measurement and analytical techniques for some of the key pollutants, including recent measurement techniques using low-cost sensors, particularly for PM. The techniques are similar across the world with some minor differences in operating conditions of analytical instrumentation. Some of these are noted in this section.

3.4.1 Priority Pollutants

Particulate Matter (PM)

Standard methods for PM measurement include pulling air through a pre-weighed blank filter for a specified period followed by measuring the mass of particles on the filter.[44] Particle mass is obtained by taking the difference between post- and pre-sampling mass measurements. The sampling configuration includes a size selective inlet that screens out particles larger than a specified size (e.g., 2.5 μm or 10 μm). Air is pulled through the inlet and the filter at a specified flowrate that is determined by the specifications of the inlet. The filter needs to be equilibrated at

20-23°C and 30-40% relative humidity for at least 24 hours before it is weighed on a microbalance.[45]

Recent advances in sensor technologies have led to the availability of several low-cost sensors for continuous monitoring of PM concentrations. These sensors typically measure the amount of light scattered by the particles and estimate the mass concentration based on calibrated responses for a known aerosol. Some sensors also use optical particle counters that assign the scattering signal of each individual particle to a specific size bin. Mass concentrations are then estimated based on assumed particle shape and density. Examples of such commercially available sensors include the AirBeam, Air Quality Egg , AirVisual, Awair, and PurpleAir. These sensors either save data to a secure digital card or transmit data to the cloud. Singer and Delp tested these sensors for several typical indoor sources.[46] Among those tested, the PurpleAir sensor showed the best response, as it correlated highly to a reference instrument that enabled investigators to estimate true concentrations even if the measurements were not accurate. The other sensors that showed reasonable performance included the AirBeam, Airvisual, and Foobot. Similar performance has been observed with the PurpleAir sensor for outdoor measurements.[47] The study found that these sensors were not suitable for detecting particles smaller than 0.3 μm in diameter (i.e., the ultrafine particles); however, because common indoor sources of ultrafine particles also had particles in the larger size bins, the study concluded that such measurements may still be useful for detecting and eliminating particle emission sources and minimizing exposures.[46]

Radon

The WHO handbook[48] summarizes recommended methods for measuring radon in air. Because radon gas is subject to significant fluctuations and temporal variations, recommendations are that the measurements be made over a longer period. Passive devices include the use of an alpha-track detector, activated charcoal detector, and electret ion chamber. Activated charcoal detectors are for short-term measurements (7 days), whereas the other two approaches can be used for periods ranging from less than a month to up to a year. Options for active measurements include a continuous radon monitor and the electronic integrating device. The continuous radon monitor can provide hourly time resolution.

Formaldehyde and Other Carbonyls

A passive sampling approach includes using a tinted Petri dish with a quartz-fiber filter coated with 2, 4-dinitrophenylhydrazine (DNPH) at the bottom[49]. Shinohara et al.[50] used DNPH sheets (Supelco, Co., MO). The HCHO and other carbonyls diffuse inside the sampler and are trapped by reaction with DNPH. The formed carbonyl DNPH derivative is then extracted with 5 mL of acetonitrile and analyzed by high performance liquid chromatography (HPLC) and UV detection at a wavelength of 365 nm[49]. Shinohara et al.[50] used ultra-sonication for 30 minutes at 24 kHz and used acetonitrile for the extraction process. Blondel and Plaisance obtained a detection limit of 1.2 μg/m^2/hr for a 6-hour sampling time with a precision of 7.8% (relative standard deviation of replicate measurements).

Active sampling is performed by pulling in air through a DNPH tube or cartridge. Many configurations are available commercially (e.g., low pressure drop, high concentration environments, etc.). For example, Blondel and Plaisance[49] used a DNPH-silica cartridge (Sep-Pak DNPH-Silica cartridge, Waters Ltd., MA) at sample flow rate of 200 mL/min for indoor and outdoor sampling. Shinohara et al.[50] used a DNPH-coated cartridge (Sep-Pak XPoSure Adlehyde Sampler, Waters Ltd., MA) at a flow rate of 800 mL/min. Flow should be verified with a certified mass flow meter (e.g., DryCal DC-Lite, Bios International Corporation, NJ). The cartridge is then analyzed by the same analysis method described above using HPLC. The cartridges are recommended to be stored after sampling in aluminized bags at 4°C until analysis[50]. Kim et al. used an ozone scrubber prior to the DNPH cartridge for sample collection using a SIBATA (Japan) MP-Σ100H sampler. Samples were analyzed in an Agilent 1100 HPLC with GL Science / Inertsil

Acrolein column using water acetonitrile (60:40) mobile phases at a slightly different detection wavelength of 360 nm.

The International Standards Organization (ISO) method (ISO 16000-3) for determination of formaldehyde and at least 12 other aromatic compounds and saturated and unsaturated aliphatic carbonyl compounds uses a similar approach (collection onto adsorbent cartridges coated with DNPH and subsequent analysis by HPLC and detection by UV absorption) that is applicable for long-term (1–24 h) or short-term (5–60 min) sampling of air and can quantify concentrations between 1 μg/m^3 to 1000 μg/m^3. ISO 16000-3 applies to the determination of:

- formaldehyde
- acetaldehyde
- acetone
- benzaldehyde
- butyraldehyde
- valeraldehyde
- 2,5-dimethylbenzaldehyde
- capronaldehyde
- isovaleraldehyde
- propionaldehyde
- o-tolualdehyde
- m-tolualdehyde
- p-tolualdehyde
- benzene
- Other VOCs

VOCs are sampled passively by adsorbents such as a Carbotrap B (Supelco, CO., MO). The adsorbed VOCs are then thermally desorbed and analyzed using gas chromatography (GC)-mass spectrometry (MS). Active sampling is performed using Carbotrap B-filled stainless steel tubes (Perkin Elmer Inc.). The tubes and traps are stored in aluminized bags at 4°C until analysis.

For the thermal desorption and analysis, Shinohara et al.[50] used the following settings:

10 min desorption time, 300°C desorption temperature, 10 mL/min desorption flow, 5°C second trap temperature, 320°C second desorption temperature, and outlet split ratio of 1:15. They used an HP5-MS capillary column with an initial GC oven temperature of 40°C maintained for 4 min, and then increased at a rate of 10°C/min to 280°C. Kim et al. used slightly different settings for their samples in Korea: 10 min desorption time, 260°C, second desorption temperature of 280°C

for 45 min, GC oven temperature of 35°C for 2 min, followed by a 15°C/min ramp up to 95°C, then a 2.5°C/min ramp up to 105°C and a 5°C/min ramp up to 250°C. They used an HP-VOC 60 mm by 0.32 mm column.

Total Microbes

Although there is no simple way to identify or quantify bacteria and viruses, the term "total microbes" is generally used when referring to bacteria. The standard method for determining total microbes in the air is to culture onto agar plates designed to encourage the growth of bacteria (e.g., tryptic soy agar) and mold or other types of fungi (e.g., potato dextrose agar). Because Legionella bacteria are such fastidious organisms, they will not grow on tryptic soy agar. They require a special medium called buffered charcoal-yeast extract. Therefore, if there is a specific desire to evaluate for Legionella, this medium will have to be used.

Fungal cultures are incubated at 25°C for 3–5 days, and bacterial cultures are incubated at 25°C for 3–5 days and at 37°C for 1–2 days. Colonies are counted from all plates to determine colony forming units, and the concentration is calculated using the volume of air sampled. In addition to total microbe counts, dominant colony morphologies can be determined for both fungi and bacteria. For fungi, identification at the genus level is possible by using microscopy to assess colony morphology and conidia structure. However, for specific bacterial identification, either biochemical or molecular methods are required.

NO_2

The standard method for measuring NO_2 (Appendix 3: 40 CFR Part 50, Appendix F) is also based on the chemiluminescence principle used for ozone. NO_2 is measured indirectly by photometrically measuring the light intensity, at wavelengths greater than 600 nm, resulting from the chemiluminescent reaction of NO with ozone. NO_2 is first quantitatively reduced to nitric oxide (NO) by means of a converter. NO reacts with ozone to form NO_2. This measures total oxides of nitrogen (NOx). A sample of the input air is also measured without having passed through the converter and gives an estimate of NO in the sample. The difference between the latter NO measurement and the former measurement provides the final NO_2 measurement. Passive methods are also available for NO_2 measurement[51]. A filter is impregnated with a standard solution prepared by mixing 7.90 g NaI with 0.88 g NaOH into 100.0 ml methanol. NO_2 reacts with iodide ions to form nitrite ions. Nitrite is then analyzed using ion chromatography by extracting nitrite from filters into triethanolamine solution.

3.4.2 Other Pollutants

CO

The standard method for measuring CO (Appendix 4: 40 CFR Part 50, Appendix C) uses non-dispersive infrared (NDIR) detection. CO absorbs infrared radiation at 4.6 μ. The absorption is quantified by using a suitable photometer detector. The infrared radiation is sent through a gas filter alternating between CO and nitrogen, after which it passes through the optical bench with the sample. The CO in the sample is detected and measured by an infrared detector that compares the difference between the reference and sample absorption.

Ozone

A standard method for measuring ozone (Appendix 5: 40 CFR Part 50, Appendix D) continuously is the chemiluminescence method. In this method, the instrument measures the intensity of the chemiluminescence released by reaction of ozone with a known quantity of ethylene (now obsolete) or NO. The chemiluminescence is proportional to the ozone concentration and is measured with a photomultiplier tube detector.

A passive sampling approach uses a filter material coated with sodium nitrite. The nitrite on the filter reacts with ozone to form nitrate, which is then detected by ion chromatography. The exposed filter is extracted with ultra-pure (Milli-Q) water, and the filter extract is analyzed by ion chromatography to determine the nitrate ion concentration, which is used to calculate the total amount of ozone collected. An example of such a commercially available passive sampler is the Ogawa badge. Because the nitrite will be present at very high concentrations on the filter material, the ion chromatography analysis must be optimized to obtain a good resolution that will adequately separate the nitrite and nitrate peaks for quantification.[52]

3.5 Identified Gaps

A review of literature on baseline conditions indicated that $PM_{2.5}$, PM_{10}, radon, formaldehyde, benzene, mold, and NO_2, are priority pollutants. In Abu Dhabi, ETS and incense use are important sources that would contribute to a combination of PM and VOCs. The survey responses also indicated agreement with this list of pollutants. Legionella, a specific type of bacteria, may be of concern in certain indoor spaces. From an IAQ perspective, these pollutants are important in Abu Dhabi and should receive immediate attention.

Existing policies in Abu Dhabi do not directly regulate air pollutants in residences. ETS is regulated in public places, and requirements for tight sealing also ensure that smoke from inside houses does not leak into public places. However, there is no information on how this is monitored. Regulations do not require monitoring (e.g., of PM) in indoor environments or in public portions of indoor areas to track smoke leakage from smoking areas. This level of regulation is similar to or better than policies in other countries.

Through the Estidama Pearl Rating System Green Building initiative, Abu Dhabi has good requirements for building ventilation and low-emitting materials. While policies in some countries specify ventilation requirements in terms of air exchange rates, the Estidama Pearl Building

Rating System requires both minimum fresh air and minimum separation distances between air intake and exhaust, which must be established in accordance with ASHRAE. Further, the optional use of CO_2 sensors is also addressed so that dynamic management of air exchange can maintain CO_2 concentration below 1000 ppm. However, this policy applies only to new buildings that require this certification. Just using a CO_2 metric may result in air exchange rates less than those of best practice guidance.

Further, the Estidama Pearl Building Rating System requirements may be mandatory or optional depending on the nature of the credit. Estidama Pearl Rating System optional credits align with specifications of VOC and formaldehyde emissions that are equivalent to some of the strongest limits imposed in the U.S. and Europe. Some specifications by the SCAQMD had new lower limits becoming effective in 2023, while the Estidama specifications reflect the existing limits used by SCAQMD.

Chapter 4: “Review of the Scientific Evidence Base on the Link Between IAQ and Health” & “Baseline Parameters and Health-Based Indicators and Targets for Indoor Air Quality”

A. Review of the Scientific Evidence Base on the Link Between IAQ and Health

1. Introduction

The Abu Dhabi Public Health Center (ADPHC) Indoor Air Quality project also covered a review of the literature to assess the need for modifying elements of the *United Arab Emirates Environmental Burden of Disease Model* (*UAE EBD Model*) indoor air pollution module. A systematic international literature review was performed on the relationship between residential indoor air quality (IAQ) and human health and on assessments of exposure to indoor air pollutants in residential settings.

2. Approach

A prior review of the scientific evidence base on the relationship between residential IAQ in Abu Dhabi Emirate and the health of Abu Dhabi residents, published by MacDonald Gibson et al. in 2013, was commissioned by the UAE government as part of an environmental health strategic planning project intended to assess the burden of disease in the nation attributable to environmental pollution. This research team developed a computer simulation model, the *UAE EBD Model*, which combines UAE public health data with environmental pollutant concentrations and epidemiological literature that estimates the relative risks of illnesses from exposure to eight indoor air pollutants: particulate matter (PM) less than 2.5 microns ($PM_{2.5}$), PM less than 10 microns (PM_{10}), radon, benzene, formaldehyde, environmental tobacco smoke (ETS), mold, and incense combustion products.

About the model

The initial research team constructed a computer simulation model called the *UAE EBD Model* to link data on environmental pollutant concentrations with new UAE public health data and with epidemiologic studies that estimate the relative risks of various illnesses caused by pollutant exposures. This model is the first to implement a comprehensive, national-scale EBD analysis in a flexible computer simulation platform that reflects uncertainty in the estimates and that can be readily updated in the future as conditions change and new local data are collected.

The model is designed to support policy analyses that compare the effectiveness of alternative options for reducing environmental risks to health. The project focused on environmental risks that are within the mandate and capability of the Environment Agency—Abu Dhabi (EAD) and Department of Health—Abu Dhabi (DOH) to address. Specifically, it covered the following six categories of risk, corresponding to six different exposure routes: outdoor air pollution, indoor air pollution, occupational exposures, drinking water contamination, coastal water pollution, and global climate change. This list of risk factors includes all those in the World Health Organization's (WHO) preliminary estimates except for indoor air pollution due to solid fuel use, as solid fuel is no longer used for cooking in the UAE. Pollutants for each exposure route that were relevant to the UAE but were not considered in the previous WHO estimates were also included.

The scope of potential pollutant-exposure route combinations were narrowed through a two-step process. First, the team conducted preliminary risk assessments for candidate pollutant-exposure route combinations identified by the EAD and the WHO Center for Environmental Health Activities for the Eastern Mediterranean Region. Then, the assessment results were presented at workshops involving government environment and health officials, faculty at local universities, international experts, local industries, and environmental groups. Participants were led through a systematic process, developed through previous research, to prioritize the pollutant-exposure route combinations for consideration. Stakeholder engagement in the selection of risks to consider was essential because the results were intended to inform future UAE strategic planning. EBD estimates for two health outcome categories were provided—mortality and morbidity—with the latter expressed as number of healthcare-facility visits. Healthcare facility visits include all patient use of hospitals, doctors' offices, and pharmacies. To support this analysis, DOH compiled death records for Abu Dhabi Emirate for 2008. The records included 2,949 deaths listed by cause (by ICD-10 code), time, location, age, gender, and nationality. This database includes all deaths reported in Abu Dhabi for the study year. DOH considers the death notification rate to be 100% because it is not legal to bury, cremate, or expatriate a body without a death certificate. Hence, death rates estimated from this dataset should be very accurate. Comparable information was not available from other emirates. Baseline death information for the other emirates was estimated by calculating death rates for gender-citizenship groups in Abu Dhabi and then applying those rates to population estimates for those same demographic groups in the other emirates.

DOH also provided patient encounter records for the diseases of interest in this study from Abu Dhabi's largest health insurance provider, Daman, which covers 73% of the emirate's population. These data were used as a surrogate for morbidity estimates, as they provided the most accurate and comprehensive database of illness incidences available for this research. Prior to 2008, Abu Dhabi lacked standards for medical records coding; hence, the dataset employed in this research is the first in Abu Dhabi to be compiled and quality-assured according to international best practices in medical records management. The records included the date of encounter, ICD-9 code for the corresponding illness, healthcare facility name, and patient demographic information (age, gender, citizenship). Patient identifiers were not provided. Noninfectious disease healthcare facility visit records were provided for 2008 (162,228 visits recorded by Daman). Like the mortality data, the health insurance claims data were scaled to cover the entire UAE population.

EBD Estimation Method

To estimate the burden of disease that was due to each combination of exposure pathway and pollutant, researchers used the ‘‘population attributable fraction’’ (PAF) approach. The PAF is the proportion of reduction in disease or mortality that would be expected if exposure to a pollutant were reduced to an alternative (known as ‘‘counterfactual’’) level and can be computed from the following equation

$$PAF = \frac{\int_{x=0}^{m} RR(x)P(x)dx - \int_{x=0}^{m} RR(x)P'(x)dx}{\int_{x=0}^{m} RR(x)P(x)dx}$$
$$= \frac{\sum_{i=1}^{n} RR(x_i)P(x_i) - \sum_{i=1}^{n} RR(x_i)P'(x_i)}{\sum_{i=1}^{n} RR(x_i)P(x_i)}$$

In this equation, x is the exposure level; RR(x) is the relative risk at exposure level x; P(x) is the population distribution of exposure; P’(x) is the alternative or counterfactual distribution of exposure; m is the maximum possible exposure level; and n is some finite number of discrete exposure intervals. For this study, the counterfactual exposure level was the elimination of all pollutants to background levels. Background levels were assumed equal to zero for all exposure pathways except for outdoor air, for which background concentrations were represented as uniform distributions with parameters (10, 90) mg/m^3, (5, 35) mg/m^3, and (0, 25) ppb for PM_{10}, $PM_{2.5}$, and O_3, respectively. The first parameter represents the lower bound and the second the upper bound of the distribution. Researchers estimated the EBD separately for each exposure route (i.e., we assumed all other exposure routes were unchanged while exposures via the given route were decreased). For the indoor air exposure route, mold, environmental tobacco smoke, and formaldehyde in indoor air all can exacerbate asthma in children; therefore, estimates of the total PAF for that exposure route can be calculated from the equation

$$PAF = 1 - \prod_{i=1}^{3} (1 - PAF_i)$$

where PAF_i is the PAF for pollutant i (mold, environmental tobacco smoke, or formaldehyde). This equation assumes that the exposures to the three pollutants are uncorrelated and that the pollutants act independently in triggering asthma.

Focusing on the IAQ parameter, the eight indoor air pollutants were chosen based on a review of the epidemiological literature that consistently showed statistically significant positive associations between indoor air pollutant exposure and adverse health effects. The model combines this information to estimate the number of annual episodes of adverse health effects and mortalities that are attributable to different types of pollution.

As stated earlier, the *UAE EBD Model* separately considered six categories of pollution: outdoor air pollution, indoor residential air pollution, occupational exposures, drinking water contamination, coastal water pollution, and climate change. Each category of pollution has its own module, and each module can be updated as local data on environmental exposures are collected or new relative risk estimates on the relationship between health effects and pollutant exposures are produced, allowing researchers to continue to update the model through time.

Since the publication of the *UAE EBD Model*, there has been ongoing global scientific research into the health effects of indoor air contaminants of emerging concern as well as continued assessments of exposure to indoor air contaminants in residential settings. Furthermore, researchers have continued to estimate the relationships between contaminants of known concern and human health, producing studies that quantify the associations between contaminant exposure and development or exacerbation of diseases. The purpose of this literature review is therefore to uncover the information necessary to modify the IAQ module in the *UAE EBD Model* by answering the following three questions:

1. *What contaminants are consistently demonstrated in the literature to have a positive association with adverse health effects that are not currently considered in the UAE EBD Model?*

2. *What epidemiological research on the relationship between exposure to indoor air contaminants and health endpoints can be added to or modify the UAE EBD Model indoor air module?*

3. *What, if any, literature is available on measurements of exposure to indoor air contaminants that could be more accurate than the exposure information used in the UAE EBD Model?*

To answer these questions, two systematic literature reviews were conducted following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) framework (PRISMA Statement, 2015). The aim of the first literature review was to review the international literature regarding the relationship between residential IAQ and human health. Through this first literature review, the first two questions of the review were addressed: what contaminants are consistently demonstrated in the literature review to have a positive association with negative health effects, and what epidemiological research quantifying the relationship between exposure to indoor air contaminants and health endpoints has been published since the publication of the *UAE EBD Model*?

2.1 Literature Review on Questions 1 and 2: Health Effects Search Strategy

PubMed Central, EBSCO Indiana University, and the World Health Organization Library databases were searched using the advanced search builder feature following the PRISMA framework. Table 6 shows the terms used in each search; all combinations of the terms were searched.

Table 6: Search terms used in literature review on health effects of IAQ contaminants

Term 1	Term 2	Term 3
Indoor air pollution	Risk	Health
IAP	Concern	Illness
Indoor air pollutants		Mortality
Indoor air contaminants		Disease
		Premature deaths

Note: All combinations of these three terms were searched.

2.1.1 Inclusion Criteria

Peer-reviewed, English-language articles published in academic journals between 2008 and 2020 were included. Only articles on health effects of indoor residential air pollutants in developed nations were included, as residents would have lifestyles and residential conditions similar to those of the UAE. Articles that were not published in English were excluded, as were studies on outdoor air pollution and IAQ in occupational, religious, or commercial settings. Studies conducted on health effects of contaminant sources that are not applicable to the UAE, such as health effects of PM from solid fuel combustion, were also excluded. Studies that were included in the full-text review were synthesized by pollutant and associated health effects.

2.1.2 Data Extraction

For each study, data collected included the indoor air contaminant of concern, the country of publication of the study, the type of study, the health effect(s) considered, notes regarding the study design and conclusions, and whether a statistically significant association was found between exposure to a contaminant and a health effect. Studies were then grouped by contaminant to evaluate all health effects potentially associated with exposure to contaminants of concern. Types of study included qualitative literature reviews, epidemiological studies, epidemiological meta-analyses, and risk assessments.

For each epidemiological study and epidemiological meta-analysis considered, the following information was recorded: information on the study's population, health endpoints considered, the relative risk estimate or odds ratio, 95% confidence interval, and the unit exposure to which the relative risk estimate or adjusted odds ratio applies. Relative risk estimates or odds ratios were extracted only from epidemiological studies that found statistically significant associations between health effects and contaminant exposure.

2.2 Literature Review on Question 3: Contaminant Exposure Search Strategy

PubMed Central, EBSCO Indiana University, and World Health Organization Library databases were searched. Two separate searches were used to identify literature on household measurements or exposure assessments to indoor air contaminants. Table 7 shows the origin of pollutant measurements or reported exposure to contaminants used in the *UAE EBD Model* indoor air module and the related focus of our search strategy. Benzene was the only pollutant with measurements not available for the UAE at the time of publication of the *UAE EBD Model*. Therefore, the first search was an international literature review for residential measured benzene concentrations published after 2008 in developed nations. The second literature review focused on residential measured concentrations or exposure to the remaining contaminants (PM, formaldehyde, radon, ETS, incense combustion products, and mold) published after 2008 in the Arabian Gulf nations of the UAE, Saudi Arabia, Oman, Kuwait, Bahrain, or Qatar. Table 8 shows the search terms used to identify literature published on measured benzene concentrations, and Table 9 shows the search terms used to identify literature published on measured concentrations or percent of population exposed to PM, formaldehyde, radon, ETS, incense combustion products, and mold.

Table 7: Contaminant concentration or exposure source in original UAE EBD model

Pollutant	UAE EBD Model Source	Search Strategy Geographic Focus
Benzene	Compiled from international literature estimates	International literature
ETS	Percent household exposure estimated in UAE survey (Yeatts, et al., 2012)	Regional or national
Formaldehyde	Measurements taken in the UAE (Yeatts, et al., 2012)	Regional or national
Incense combustion products	Percent household exposure estimated in UAE survey (Yeatts, et al., 2012)	Regional or national
Mold	Percent household exposure estimated in UAE survey (UAE University, 2002)	Regional or national
$PM_{2.5}$	Measurements taken in the UAE (Yeatts, et al., 2012)	Regional or national
PM_{10}	Measurements taken in the UAE (Yeatts, et al., 2012)	Regional or national
Radon	Measurements available for Abu Dhabi City as published in MacDonald Gibson et al. (2013)	Regional or national

Abbreviations: ETS, environmental tobacco smoke; $PM_{2.5}$, particulate matter < 2.5 microns; PM_{10}, particulate matter < 10 microns; UAE EBD, United Arab Emirates Environmental Burden of Disease.

Table 8: Search terms used in literature review on measured indoor benzene concentration

Term 1	Term 2
Benzene	Household air concentration
	Indoor air concentration
	Residential air concentration

Note: All combinations of these terms were searched

Table 9: Search terms used in literature review on measured concentration or exposure to remaining indoor air contaminants

Term 1	Term 2	Term 3
Particulate matter	Household air concentration	Arabian Gulf nations
PM	Indoor air concentration	UAE
Formaldehyde	Residential air concentration	Abu Dhabi
Radon	---	Saudi Arabia
Environmental tobacco smoke	---	Oman
Second-hand smoke	---	Kuwait
Mold	---	Bahrain
Incense use	---	Qatar
Incense smoke	---	---

Note: All combinations of these terms were searched.

2.2.1 Inclusion Criteria

For benzene, only studies on household concentrations in developed nations were included. Studies had to be published in English in peer-reviewed academic journals. Studies documenting personal exposure that included occupational or transportation indoor settings were not included. For the remaining contaminants (PM, formaldehyde, radon, ETS, incense combustion products, and mold), only studies that had been conducted in the nations of UAE, Saudi Arabia, Bahrain, Oman, Kuwait, or Qatar were considered.

2.2.2 Data Extraction

The literature review did not reveal any studies that recorded measured concentrations of PM, formaldehyde, or radon or exposure to incense combustion products or mold in countries in the Arabian Gulf. Therefore, only studies regarding ETS and benzene were considered for extraction. For benzene, study location, number of samples, sampling period, mean, and standard deviation of measurements were recorded. Benzene concentrations were weighted by the size of the study and pooled to create a pooled mean estimate of benzene concentrations. For ETS, information on the percent of the UAE population exposed to second-hand smoke was recorded.

3. Results

3.1 Research Question 1

<u>What contaminants are consistently demonstrated in the literature to have a positive association with adverse health effects that are not currently considered in the *UAE EBD Model* indoor air pollution module?</u>

Table 10 shows the number of all studies included in the review that evaluated or summarized results about health effects sorted by pollutant; whether a pollutant was included in the *UAE EBD Model* is also indicated in Table 10. The majority of studies focused on the health effects associated with pollutants considered in the model, including mold, ETS, radon, nitrogen dioxide, formaldehyde, and incense combustion products. Of contaminants not modelled in the original *UAE EBD Model*, nitrogen dioxide or its main source, natural gas stove cooking, had the most qualitative and quantitative assessments of the relationship between concentration and health effects. Many other contaminants that were not included in the *UAE EBD Model,* some of which have IAQ guidelines established by the WHO (WHO, 2010), had fewer than five published studies that assessed their health effects through either qualitative reviews or epidemiological studies.

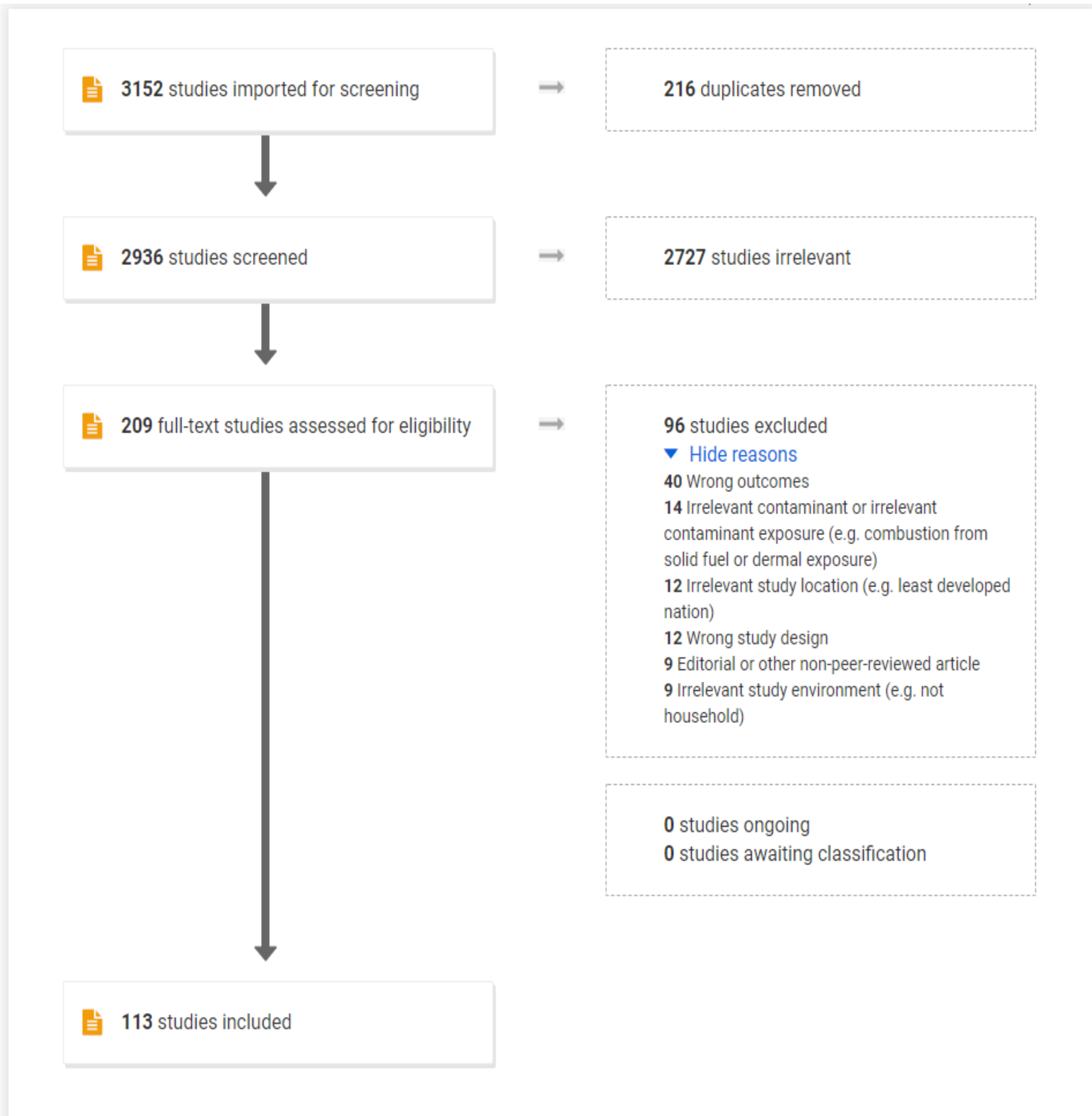


Figure 3: PRISMA flowchart showing results of literature search and screening process (provided by Covidence)

Contaminants that were not included in the original *UAE EBD Model* were excluded from consideration in modifying the model based on the following criteria:

A. No epidemiological studies evaluated the health impacts of this pollutant,

B. Epidemiological studies evaluated a health effect that cannot be captured by the *UAE EBD Model* (e.g., general symptoms like sleeplessness, eye irritation, or forgetfulness),

C. Epidemiological studies revealed no association or inconsistent findings about the exposure to indoor concentrations of a contaminant and adverse health effects,

D. Fewer than three epidemiological studies found a significant positive association between exposure to a pollutant and the same adverse health effect, or

E. A qualitative review declared that not enough information was available to establish a positive association between exposure to a contaminant and adverse health effects.

In other words, inclusion of a contaminant in the model required the publication of at least three epidemiological studies that found a positive association between exposure to a contaminant and the same health effect. For example, some contaminants were excluded because they had only one epidemiological study showing a positive association between exposure to that contaminant and different health effects.

Table 10: Number of studies included in the literature review by contaminant of focus

Contaminant	Number of Studies[a]	Included in Original UAE EBD Model
Mold	20	Yes
Environmental tobacco smoke (ETS)	19	Yes
Radon	16	Yes
Formaldehyde	13	Yes

Natural gas stove and nitrogen dioxide (NO_2)	13	No
Particulate matter	11	Yes
Incense combustion products	7	Yes
Benzene	5	Yes
Polycyclic aromatic hydrocarbons	5	No
Toluene	4	No
Trichloroethylene	3	No
Air fresheners	2	No
Cooking fumes (excluding natural gas stoves)	2	No
Microbial volatile organic compounds	2	No
Phthalates	2	No
Tetrachloroethylene	2	No
Xylene	2	No
Candles	1	No
Carbon monoxide (CO)	1	No
CO_2	1	No
E-cigarettes	1	No
Ozone	1	No
Polybrominated diphenyl ethers (PBDES)	1	No
Polychlorinated biphenyls (PCBs)	1	No

[a]The number of studies sums to more than the 113 papers included in the literature review because some publications focused on more than one contaminant.

The set inclusion and exclusion criteria were a drawback. . Moreover, many other pollutants were also excluded because they lacked relevant studies. Indeed, 44 studies of other pollutants were excluded because of a lack of studies or inability to conclude positive association.

Table 11 shows contaminants that were not considered in the originally published *UAE EBD Model* indoor air module and the reason for adding or excluding each from the modified model. Most contaminants considered had no associated epidemiological studies that demonstrated a positive association between a health effect and the contaminant. As Table 10 shows, the only contaminant that had consistent epidemiological literature was NO_2 and natural gas stove cooking because one meta-analysis of 41 epidemiological studies established a significant association between both NO_2 and exposure to natural gas stove cooking and childhood asthma (Lin, Brunekreef, & Gehring, 2013).

It is important to reiterate that studies often analyzed the health effects of NO_2 and natural gas cooking together, as natural gas cooking is a major source of indoor NO_2. The remainder of the contaminants did not meet the established criteria, so only natural gas stove cooking will be added as a contaminant to the *UAE EBD Model* indoor air pollution module.

Table 11: Exclusion rational regarding addition of contaminants to the UAE EBD model / indoor air pollution model

Contaminant	Reasons for Exclusion
Air fresheners	A
Candles	B
Carbon monoxide (CO)	B, C
Cooking fumes (excluding natural gas stoves)	A
CO_2	B
E-cigarettes	A
Microbial volatile organic compounds	B, C
Ozone	A
Phthalates	E
PBDEs	E

PCBs	E
Polyaromatic hydrocarbons	C, D
Tetrachloroethylene	B
Toluene	B, C
Trichloroethylene	B, D
Xylene	A

A. No epidemiological studies evaluated the health impacts of this pollutant.

B. Epidemiological studies evaluated a health effect that cannot be captured by the UAE EBD Model (e.g. general symptoms like sleeplessness, eye irritation, or forgetfulness).

C. Epidemiological studies revealed no association or inconsistent findings about the exposure to indoor concentrations of a contaminant and adverse health effects.

D. Fewer than three epidemiological studies found a significant positive association between exposure to a pollutant and the same adverse health effect.

E. A qualitative review declared that not enough information was available to establish a positive association between exposure to a contaminant and adverse health effects.

3.2 Research Question 2

What epidemiological research on the relationship between exposure to indoor air contaminants and health endpoints can be added to or modify the *UAE EBD Model* indoor air module?

To address the second research question, the included studies (113) were narrowed down to only epidemiological studies that measured the risk of a health effect in populations exposed to $PM_{2.5}$, PM_{10}, radon, formaldehyde, benzene, ETS, mold, incense combustion products, and natural gas cooking in indoor settings. Epidemiological studies estimate the risk of developing an adverse health effect in the population exposed to a pollutant compared to an identical, unexposed population (using relative risk).

Only epidemiological studies that evaluated diseases with corresponding international health codes, known as ICD-10 codes, were isolated for consideration. For example, studies evaluating the association between a pollutant and wheezing or stuffy nose were not included in the analysis, as wheezing and stuffy nose are symptoms of various diseases and are not alone considered diseases. A total of 65 of the 113 studies included in the analysis were epidemiological studies. Of these 65 epidemiological studies, only 38 evaluated the relationship between exposure to a pollutant and a disease.

Particulate Matter

Eleven papers were included in the overall analysis for PM. Seven of these studies aimed to estimate a quantitative relationship between exposure to residential indoor PM of all sizes and certain health effects. Two studies found a positive relationship between exposure to indoor residential fine particulate matter ($PM_{2.5}$) and exacerbation of chronic obstructive pulmonary disease (COPD) symptoms (Hansel et al., 2013; McCormack et al., 2016). Two other studies found a positive relationship between exposure and heightened blood pressure and heart rate (Lin et al., 2009; Rumchev et al., 2018), which are important factors in the development of cardiovascular disease. Overall, no epidemiological studies uncovered in this literature review revealed estimates between the presence of a disease and exposure to either $PM_{2.5}$ or PM_{10}, so no new epidemiological parameters for the relationship between indoor PM exposure and health effects will be added to the *UAE EBD Model*.

Radon

Sixteen articles were included in the analysis of the health effects attributable to residential radon. Twelve of these studies were epidemiological studies that aimed to quantitatively describe a relationship between residential radon exposure and the elevated risk of developing or exacerbating various health risks. Six of the epidemiological studies were case-control studies that examined the association between residential radon exposure and lung cancer overall or specific types of lung cancers. Two studies assessed the relationship between residential radon exposure and childhood leukemia, with one study in a cohort of Norwegian children finding no association (Kollerud, Blaasaas, and Claussen, 2014).

An earlier meta-analysis of studies evaluating the relationship between childhood leukemia and residential radon exposure was conducted by Raaschou-Nielsen et al. (2008); the authors evaluated 12 ecological studies and 7 case-control studies and concluded that a relationship between childhood leukemia and residential radon might exist but is weak. Due to the lack of consistency in case-control studies regarding the relationship between residential radon exposure and childhood leukemia, this study will not include childhood leukemia as a health effect from the radon button in the *UAE EBD Model* indoor air module.

Two other ecological studies that found positive associations between residential radon exposure and hospital admissions in COPD patients (Barbosa-Lorenzo et al., 2017) and the development of esophageal cancer (Ruano-Ravina et al., 2014) were excluded because the authors of the studies stated that their findings from ecological studies should be extrapolated with caution. From the 12 studies, only one meta-analysis of case-control studies evaluating the relationship between radon and lung cancer will be used to modify the *UAE EBD Model*. Zhang et al. (2012) conducted a meta-analysis that showed a significant association between residential radon exposure and lung cancer from pooled estimates of 22 case-control studies; this study's relative risk estimates will replace the estimates from a previous analysis used in the model (Darby et al., 2005).

Benzene

Five studies were included in the overall analysis of health effects associated with indoor levels of benzene and health; only two of these five studies were epidemiological studies. One epidemiological study found no association between indoor benzene concentration levels and breathlessness in the elderly (Bentayeb et al, 2013). Another study found no association between indoor concentrations of benzene and persistent cough, wheezing, or lower respiratory tract infections in infants; however, the authors of that study noted that 42% of sampled indoor levels of benzene exceeded 1.7 $\mu g/m^3$ (Ferrero et al., 2017), which is the concentration the WHO states is associated with a 1/100,000 elevated lifetime risk of leukemia (World Health Organization, 2010). No new epidemiological parameters will be added to the benzene section of the *UAE EBD Model* indoor air module owing to the lack of epidemiological literature revealed in this search. It is important to note that although benzene is classified by the International Agency for Research on Cancer (IARC) as group 1, human carcinogen (International Agency for Research on Cancer, 2018), this literature review revealed no studies estimating the epidemiological parameters that are necessary for linking exposure to indoor benzene with cancer in the *UAE EBD Model*.

Formaldehyde

Thirteen studies identified in the literature review discussed health effects related to indoor formaldehyde exposure. Of these 13 studies, 7 were epidemiological studies that estimated the relationship between indoor formaldehyde exposure concentration levels and the presence of health effects in a population. Two studies found a positive association between sick-building syndrome symptoms and formaldehyde exposure (Takigawa et al., 2009; 2010). Sick-building syndrome referred to non-specific, subjective health effects such as irritation of eyes, nose, and throat; headaches; and general fatigue. Therefore, these associations will not be added to the model.

Four studies evaluated the relationship between indoor formaldehyde exposure and symptoms such as wheezing, breathlessness, and general respiratory symptoms like coughing, nasal irritation, and allergic rhinitis. One study found a positive association between indoor formaldehyde levels and lower respiratory infections in a cohort of infants (i.e., up to a year in age) in Paris, France (Roda et al., 2011). The epidemiologic parameters from this study (Roda et al., 2011) will be added to the updated environmental burden of disease model given the strength of the cohort study and supporting evidence in other studies.

Mold

A total of 21 studies considered or discussed the health effects of indoor mold. Five were qualitative reviews, and 16 were epidemiological studies that evaluated the relationship between adverse health effects and exposure to indoor mold or dampness. One of these epidemiological studies evaluated the relationship between asthma and mold spore counts and found no association (Holme et al., 2010). Eight of these epidemiological studies evaluated the relationship between mold and asthma or asthma severity in either children or adults. Preference was given to meta-analyses; therefore, the two meta-analyses were examined. Tischer, Chen, and Heinrich (2011) included 61 studies in their meta-analysis and found that indoor visible mold was associated with childhood asthma for children of all ages. This meta-analysis included more studies than the epidemiological study currently in the *UAE EBD Model*—Antova et al. (2008)—and included asthma in children of all ages. Therefore, this study will be used to modify the epidemiological parameters for mold and childhood asthma. Norbäck et al. (2013) examined adult-onset asthma across 13 European studies and found a positive association between exposure to visible mold and adult-onset asthma in adults who were not diagnosed with asthma at the beginning of the study. The sample size of this epidemiological study was larger than that of Jaakkola (2002), the study currently providing the relative risk information for indoor mold and adult asthma in the *UAE EBD Model*. Therefore, the data from Norbäck et al. (2013) will modify the model.

Incense Combustion Products

Six studies in total were examined in the full analysis of this literature review. Two studies analyzed the components of Arabian incense combustion but did not analyze the health effects associated with these components (Cohen, 2013; Dalibalta, 2015). Four studies focused on the health effects associated with burning of Chinese or Arabian incense indoors. Yeatts et al. (2012) found that daily burning of bakhour incense was associated with self-reported headaches, difficulty concentrating, and forgetfulness in survey respondents from the UAE. A community survey conducted in Oman found that burning bakhour in homes was associated with wheezing among asthmatic children but did not identify burning as the cause of asthma (Al-Rawas et al., 2009).

Two studies analyzed the association between burning of Chinese incense and cancers of the respiratory system. Tse et al. (2011) found that cigarette smoking and high exposure to incense had a synergistic effect on lung cancer, compared to never smokers who had never used incense or with smokers who had lung cancer but did not use incense frequently (60 days or less a year). This combined effect for smokers who also used incense frequently cannot be captured by the *UAE Burden of Disease Model*; therefore, this study was excluded from consideration in updating the model's epidemiological parameters.

Finally, a case control study in Hong Kong found an increased risk for nasopharyngeal cancer among women, but not men, who practiced daily incense burning (Xie et al., 2014). Given that the study providing the current epidemiological relationship in the *UAE EBD Model*—Friborg et al. (2008)—captures the association between incense burning and all respiratory tract cancers, including nasopharyngeal cancer, we did not include the results of Xie et al., 2014.

ETS

Five studies examined the effects of indoor smoking bans. Seven epidemiological studies estimated the relationship between adverse health effects and household exposure to indoor ETS. One study found a significant decrease in maternal mental health scores in non-smoking mothers who lived with at least one other smoker (Sobotova et al, 2011). One other study found a positive association between exposure to ETS and wheezing (Hersoug et al., 2010), whereas another found no association between exposure to ETS and wheezing in infants (Raaschou-Nielsen et al., 2010). Malinauskiene (2011) found an association between myocardial infarctions (i.e., heart attacks) and exposure to ETS in women ages 31-64. Ngu and McEvoy (2017) found an association between exposure to ETS and peripheral arterial disease in a meta-analysis of 12 studies. Both health effects are considered as cardiovascular diseases in He (1999), the epidemiological source study currently in the *UAE EBD Model*. Therefore, the study by Ngu and McEvoy will not be included in the modified *UAE Environmental Burden of Disease Model*.

Tsai et al. (2010) found that household ETS was significantly associated with early-onset asthma in children. A meta-analysis of 51 studies (Li et al., 1999) provides the relative risk estimates for the relationship between childhood asthma and ETS in the *UAE EBD Model*. Tsai et al. (2010) was an epidemiological study from one country; therefore, the relative risk estimates from the Li et al. (1999) meta-analysis will remain. Röösli (2011) found that postnatal exposure to ETS increased the risk of sudden infant death syndrome (SIDS) in a meta-analysis of six studies that controlled for maternal smoking during pregnancy.

Natural Gas Stoves and Associated Major Component, NO_2

Thirteen papers included in the overall analysis focused on health effects of either indoor NO_2 or natural gas stoves, which emit NO_2, CO, and formaldehyde. Scholars often included studies that evaluated the potential health effects associated with natural gas cooking in analyses that focused on NO_2 health effects or treated natural gas as a surrogate measure for NO_2; therefore, studies evaluating the association between adverse health effects and natural gas cooking together with NO_2 were included.

Four studies were qualitative reviews of the adverse respiratory health effects of various indoor air pollutants, including NO_2 or natural gas cooking. Two of the qualitative reviews focused on childhood asthma solely (Breysse et al., 2010; Heinrich, 2011), and the other two focused on various respiratory illnesses (Fuentes-Leonarte, Ballester, and Tenas, 2009; Hulin et al., 2012). Hulin et al. (2012) reviewed the main epidemiological studies that evaluated the respiratory effects of indoor air pollutants in industrialized countries and concluded that evidence is reliable for NO_2 being associated with the development of asthma in sensitive populations or the exacerbation of asthma. Heinrich (2011), however, categorized the association between gas use, measured indoor NO_2 concentrations, and asthma in childhood as having inadequate/insufficient evidence to infer the presence or absence of a causal relation.

Nine studies were epidemiological studies that evaluated the relationship between natural gas stoves and/or NO_2 and adverse health effects. Two of those found a positive association between worsened COPD symptoms and NO_2 levels indoors (Hansel et al., 2008; McCormack et al., 2016). Notably, McCormack et al. (2016) studied the effect of temperature on exacerbation of COPD symptoms (coughing, wheezing, breathlessness) and found that the adverse effect of temperature on these outcomes increased with higher concentrations of indoor fine PM and NO_2.

Two other studies examined the association between indoor levels of NO_2 and exacerbation of symptoms in children with asthma. One of those studies reported a positive association for some worsened respiratory symptoms of asthma and no associations for others (Hansel et al., 2013). Another study found a positive association between increased asthma severity and indoor NO_2 levels (Belanger et al, 2013). Two other studies found no statistically significant association between minor respiratory symptoms (coughing, wheezing, and lower respiratory infections) in infants under 1 year of age (Esplugues, 2011; Raaschou-Nielsen O. H., 2010).

One meta-analysis reported an association between gas cooking in homes and reduced lung function in children (Moshammer et al., 2010). In a case-control study from Lithuania, Malinauskiene et al. (2011) found a significant association between indoor gas stove usage and incidence of myocardial infarction (i.e. heart attacks) among 34–61-year-old women. Although this study found a significant association, no others from this literature review reported a significant relationship between exposure to natural gas and myocardial infarctions; therefore, this study will be left out of the model.

Finally, in a meta-analysis published by Lin, Brunekreef, and Gehring that included 41 studies, natural gas stove cooking was significantly associated with asthma in children of all ages. This epidemiological study (Lin, Brunekreef, and Gehring, 2013) will be added to the modified *UAE EBD Model*.

Figure 4 shows the number of epidemiological studies that have evaluated the relationships between indoor air contaminants and diseases with corresponding ICD 10 codes by pollutant, as well as their conclusions. Many health effect pollutant exposure relationships were examined by only one study or one meta-analysis. As Figure 4 illustrates, the most commonly evaluated contaminant health effect relationships were asthma and mold with eight studies, and radon and lung cancer with six studies, both of which were already documented in the *UAE EBD Model*.

Figure 4 also shows the number of studies that quantified the association between exposure to a contaminant and presence of a disease. Some epidemiological studies in this figure are meta-analyses, which combine the results of multiple studies, but they are counted as only one study.

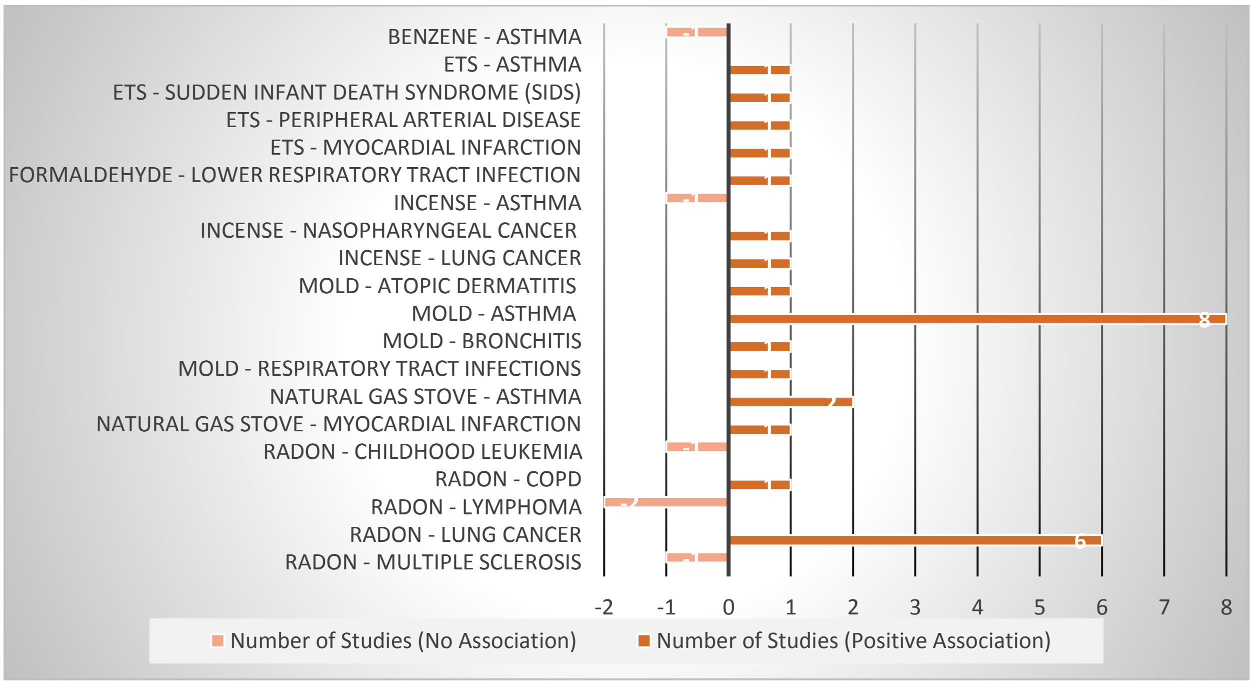


Figure 4: Epidemiological studies found in the literature review listed by pollutant. COPD, chronic obstructive pulmonary disease; ETS, environmental tobacco smoke.

Relative Risk Extraction

Finally, relative risk information was extracted from meta-analyses and studies for use in the *UAE EBD Model* when the following criteria were met:

- At least one meta-analysis of more than five epidemiological studies demonstrated a positive association between the pollutant and the same health effect,

- An epidemiological study had a larger sample size than a study evaluating the same pollutant–health effect relationship in the current *UAE EBD Model*, or

- The addition of a risk estimate from an epidemiological study had supporting evidence from other qualitative reviews.

Studies that found a positive association with one disease when an epidemiological study in the *UAE EBD Model* found an association between the same contaminant and a larger class of diseases were excluded. For example, a study that found an association between ETS and peripheral arterial disease was excluded because peripheral arterial disease is considered a cardiovascular disease, according to He et al. (1999), which establishes the epidemiological parameters between ETS and cardiovascular diseases in the *UAE EBD Model* indoor air module.

In summary, the second research question (what epidemiological research on the relationship between exposure to indoor air contaminants and health endpoints can be added to or modify the *UAE EBD Model* indoor air module) was addressed by adding only six new epidemiological relationships between health effects and exposures to pollutants. Two epidemiological studies provided relative risk information for health effects that were not included in the previous *UAE EBD Model* (Lin, Brunekreef, and Gehring, 2013; Roda et al., 2011). Three epidemiological studies will replace the relative risk information in the current *UAE EBD Model* (Norback et al., 2013; Tishcher, Chen, and Heinrich, 2011; Zhang et al., 2012). Table 12 includes the relative risk information for each contaminant and health effect that met these criteria, including the country the study was conducted in, the health effect examined, the relative risk estimate or adjusted odds ratio, the unit exposure to which the relative risk applies, and notes.

Table 12: Health effects studies by contaminant

Pollutant	Citation	Country	Health Effect	Relative Risk[a] or Odds Ratio[b] (95% CI)	Unit Exposure to Which Relative Risk Applies	Notes
Radon	Zhang et al., 2012	Meta-analysis	Lung cancer	1.07 (1.04,1.10)	100 Bq/m^3	The relative risk information from this study will replace the relative risk from Darby et al. (2005), which was used in the original *UAE EBD Model.*
Formaldehyde	Roda et al., 2011	France	Lower respiratory tract infections in infants	1.104 (1.04, 1.161)	12.4 μg/m^3	This study adds a new health effect to the formaldehyde button in the *UAE EBD Model.*
ETS	Röösli􀀀et al., 2011	Meta-analysis	Sudden infant death syndrome (SIDS)	1.75 (1.43, 2.15)	N/A	This study would add a new health effect associated with ETS to the *UAE EBD Mode*l. However, no mortalities from SIDS occurred in 2019, according to ADPHC data. Therefore, relative risk information on SIDS due to ETS was not added to the *UAE EBD Model.*
Mold	Norbäck et al., 2013	13 European countries	Asthma, adult onset	1.30 (1.00, 1.68)	N/A	The relative risk information from this study will replace the relative risk from

						Jaakkola et al. (2002), which was used in the original *UAE EBD Model.*
	Tishcher, Chen, and Heinrich (2011)	Meta-analysis	Asthma, children	1.323 (1.235, 1.573)	N/A	The relative risk information from this study will replace the relative risk from Antova et al. (2008), which was used in the original *UAE EBD Model.*
Natural gas cooking	Lin, Brunekreef, and Gehring (2013)	Meta-analysis	Asthma, children	1.267 (1.153-1.393)	N/A	This study adds a health effect to the newly added natural gas stove button in the *UAE EBD Model.*

Abbreviations: ADPHC, Abu Dhabi Public Health Centre; CI, confidence interval; ETS, environmental tobacco smoke; N/A, not available; *UAE EBD*, United Arab Emirates Environmental Burden of Disease.

[a]The relative risk of an event in this case is the probability of an adverse health effect occurring in the population exposed to a certain pollutant divided by the probability of an adverse health effect in the unexposed population.

[b]The odds ratio equals the odds that an adverse health effect will occur in the exposed population divided by the odds that the health effect will occur in the unexposed population.

3.3 Research Question (3)

What (if any) literature is available on measurements of exposure to indoor air contaminants that could be more accurate than the exposure information used in the current *UAE EBD Model*?

Benzene

Indoor concentration means and standard deviations were extracted from the 13 studies. Table 13 shows the studies, locations, number of samples, sampling period, mean measured concentration, and standard deviation of measured benzene levels taken in homes in developed nations. These estimates were pooled with the benzene measurements from previous studies included in the original *UAE EBD Model.* The updated benzene concentration estimate has a mean of 8.307 $\mu g/m^3$ and standard deviation of 8.523 $\mu g/m^3$. This estimate is lower than the pooled mean of 9.5 $\mu g/m^3$ with standard deviation of 9.46 $\mu g/m^3$ used in the original *UAE EBD Model*.

Particulate Matter, Formaldehyde, and Radon

The search for literature in the region resulted in 0 studies, so no studies were screened. Concentration information used in the original *UAE EBD Model*, which came from measurements taken in homes in the UAE (Yeatts et al., 2012) for PM and formaldehyde and taken in Abu Dhabi city (as published in MacDonald Gibson et al., 2013) for radon, will remain.

Table 13: Benzene concentration literature review

Reference	Location	Number of samples	Sampling period	Mean (µg/m³)	Standard deviation (µg/m³)
Byun et al. (2010)	Ansan, Siheung, and Seongnam, South Korea	50	24 hours	7	12.8
Chin et al. (2014)	Detroit, Michigan, USA	126	7 days	2.27	3.25
Delgado-Saborit et al. (2009)	Wales and England, United Kingdom	500	24 hours	2.2	2.5
Dodson et al. (2008)	Boston, Massachusetts, USA	83	48 hours	2.6	3.1
Du et al. (2015)	Detroit, Michigan, USA	170	7 days	2.21	2.72
Esplugues et al. (2010)	Valencia, Spain	352	15 days	2.7	6.4
Hamidin et al. (2013)	Brisbane, Australia	81	150 minutes	2.4	2.4
Héroux et al. (2010)	Saskatchewan, Canada	105	Summer, 24 hours	2.72	5.03
			Winter, 24 hours	2.06	2.73
Johnson et al. (2010)	Detroit, Michigan, USA	39	7 days	1.7	1.0
Lee et al. (2014)	Seoul, South Korea	150	30 minutes	2.8	2.0
Yang et al. (2020)	Western Switzerland	169	7 days	3.1	7.3

Yin et al. (2019)	China, 9 cities	223	7 days	2.27	3.25
Hadei et al. (2018)	Tehran, Iran, District 1	27	30 minutes	45.6	10.8
	Tehran, Iran, District 2	27	30 minutes	61.4	18.7
	Tehran, Iran, District 3	27	30 minutes	56.5	11.9
	Tehran, Iran, District 4	27	30 minutes	53.7	13.8
	Tehran, Iran, District 5	27	30 minutes	48.9	12.7

ETS, Mold, and Incense Combustion Products

Eight studies were revealed in the search, and all were excluded because they were duplicates or referenced papers (e.g., Yeatts et al., 2012), or they did not assess frequency of indoor use or presence of ETS, incense, or mold. No studies on residential frequency of use of incense or presence of mold in the UAE or surrounding region were identified in the literature search other than the one by Yeatts et al. (2012). Separate from the literature search, members of this research team identified a study that evaluated the patterns of tobacco use in the UAE Health Future (UAEHFS) pilot study (Al-Houqani et al., 2018). After the study was reviewed, the team decided to include its ETS exposure data in the *UAE EBD Model* as it is a more recent survey than that of Yeatts et al. (2012), the current source of ETS exposure in the *UAE EBD Model*.

UAEHFS acquired complete smoking data for 428 participants. Self-reported tobacco use was 35% among men and 3% among women. Approximately 30% of women and 9% of men reported some level of exposure to cigarette, midwakh, or shisha smoke at home. Most nonsmokers reported that they were not exposed to smoke in the home, but 17% did report some level of exposure. The study included individuals ages 18 to 40 but did not include children. Because the prevalence of self-reported smoking was higher among men than women in this UAEHFS pilot study, the second-hand exposure to cigarette, midwakh, or shisha smoke reported by women for male and female children will be used to update ETS exposure in the *UAE EBD Model*. Exposure estimates for mold and incense use frequency will remain the same.

Table 14 shows a summary of results and includes the mean concentration measurements or population exposed as published in the original *UAE EBD Model*, the source of those measurements, the concentrations or measurements that were ascertained in the literature review (where applicable), their sources, and a summary of whether the exposure estimate is the same or modified, sorted by pollutant.

Table 14: Contaminant concentration or exposure source in modified UAE EBD Model

Pollutant	**Original *UAE EBD Model* Concentration or % Population Exposed**	**Original *UAE EBD Model* Source**	**Literature Review Concentration or Population Exposed**	**Literature Review Source**	**Modified from the *Original UAE EBD* Model**
Benzene	Mean (SD) 9.5 μg/m^3 (9.46)	Compiled from international literature estimates (available in (MacDonald Gibson, 2013))	Mean (SD) 8.307 μg/m^3 (8.523)	International literature from 13 studies	Yes
Environmental tobacco smoke	19%	Percent household exposure estimated in UAE survey (Yeatts, et al., 2012)	Adult women, children: 30% Adult men: 9%	Al-Houqani et al. (2018)	Yes
Formaldehyde	Mean (SD) 22.26 μg/m^3 (63.6)	Measurements taken in the UAE (Yeatts, et al., 2012)	N/A	N/A	No
Incense combustion products	Daily use: 43.5% Intermittent use: 42.9% Never: 13.6%	Percent household exposure estimated in UAE survey (Yeatts, et al., 2012)	N/A	N/A	No
Mold	16%	Percent household exposure estimated in	N/A	N/A	No

		UAE survey (UAE University, 2002)			
$PM_{2.5}$	Mean (SD) 30.6 μg/m^3 (34.36 μg/m^3)	Measurements taken in the UAE (Yeatts, et al., 2012)	N/A	N/A	No
PM_{10}	Mean (SD) 92.8 μg/m^3 (144.9)	Measurements taken in the UAE (Yeatts, et al., 2012)	N/A	N/A	No
Radon	Mean (SD) 13.8 Bq/m^3 (6.6)	Measurements available for Abu Dhabi city as published in (MacDonald Gibson et al., 2013)	N/A	N/A	No
Natural gas stove cooking	N/A	N/A	17%	Percent household exposure estimated in UAE survey (Yeatts, et al., 2012)	N/A – Natural gas stove cooking was not considered in the original *UAE EBD Model*.

Abbreviations: N/A, not available; SD, standard deviation; *UAE EBD*, United Arab Emirates Environmental Burden of Disease.

4. Discussion

This literature review aimed to address three questions: what contaminants are consistently demonstrated in the literature to have a positive association with adverse health effects that are not currently considered in the *UAE EBD Model*, what epidemiological research on the relationship between exposure to indoor air contaminants and adverse health effects can be added to or modify the *UAE EBD Model*, and what literature is available on measurements of exposure to indoor air contaminants that are more accurate than information used in the original *UAE EBD Model*. This literature review was conducted to assess the need to modify the *UAE EBD Model* as part of an assessment of IAQ governance, policies, and regulations in Abu Dhabi.

Regarding the first question, results indicate that it is possible to add the contaminant of natural gas stove cooking to the *UAE EBD Model* indoor air module. Seventeen contaminants were considered for potential addition to the *UAE EBD Model,* and their associated epidemiological studies were analyzed with a set of criteria that only natural gas cooking met. Most contaminants considered for addition to the model simply had no associated epidemiological studies that demonstrated a positive association between a health effect and the contaminant. The inclusion of natural gas stove cooking as a pollutant source was supported by one meta-analysis of 41 epidemiological studies establishing a significant association between exposure to natural gas stoves and childhood asthma (Lin, Brunekreef, & Gehring, 2013). In summary, there is sufficient epidemiological information to quantify an association between exposure to natural gas stoves and childhood asthma. Information on the percentage of households exposed to natural gas stoves in homes with attached kitchens is available from a study conducted in Emirati homes (Yeatts, et al., 2012).

To answer the second research question, qualitative reviews and epidemiological studies or meta-analyses on the relationship between pollutants in the *UAE EBD Model* and health effects were reviewed. Epidemiological studies that considered health effects that were disease symptoms, such as stuffy nose or cough, but were not diseases or classes of diseases were eliminated. Relative risk information were extracted from epidemiological studies and meta-analyses that were deemed to meet the following criteria:

1. At least one meta-analysis of more than five epidemiological studies demonstrated a positive association between the pollutant and the same health effect,
2. An epidemiological study had a larger sample size than one evaluating the same pollutant health effect relationship in the current *UAE EBD Model*, or
3. The addition of a risk estimate from an epidemiological study had supporting evidence from other qualitative reviews.

Six epidemiological studies or meta-analyses met those criteria, and five were added to the model. Two epidemiological studies provided relative risk information for health effects that were not included in the *UAE EBD Model*. Lin, Brunekreef, and Gehring (2013) provided relative risk information for the relationship between exposure to natural gas cooking and childhood asthma. Roda et al. (2011) provided relative risk information for the relationship between exposure to indoor formaldehyde and lower respiratory tract infections in infants under a year of age. Three epidemiological studies will replace the relative risk information in the *UAE EBD Model* for the relationship between exposure to mold and adult asthma (Norbäck et al., 2013), exposure to mold and childhood asthma (Tishcher, Chen, and Heinrich, 2011), and exposure to radon and lung cancer (Zhang et al., 2012).

In reference to the last question, one survey was available from the UAE that can provide modified information on ETS exposure. UAEHFS found that 30% of women and 9% of men reported some level of exposure to cigarette, midwakh, or shisha smoke in the home (Al-Houqani, 2018). The mean measurements of benzene concentration from international literature were also pooled to provide an estimate of benzene concentrations in Abu Dhabi. Thus, the estimates for exposures to PM, formaldehyde, radon, ETS, mold, and incense combustion products in the *UAE EBD Model* will remain the same.

This literature review assessed the need to modify the *UAE EBD Model*, published by MacDonald Gibson et al. (2013), by including recent research regarding health effects of key indoor air pollutants, the epidemiological research regarding an association between exposure to a contaminant and health effects, and recent indoor air contaminant exposure information. The information gathered in this literature review will allow modification of elements of the indoor air module part of the *UAE EBD Model*, which estimates the number of preventable illnesses and premature deaths attributable to indoor air pollution per year in Abu Dhabi Emirate. This review has identified some critical modifications for the *UAE EBD Model* by providing the evidence to add one key indoor air contaminant, natural gas stoves; providing the relative risk information for two health effects; providing relative risk information from larger epidemiological studies for three contaminants; and updating exposure to two contaminants, ETS and benzene. Table 15 summarizes the key findings regarding modifications to the *UAE EBD Model*.

Table 15: Summary of results regarding modifications to the UAE EBD Model

Research Question	Key Results
Research Question 1: What contaminants are consistently demonstrated in the literature to have a positive association with adverse health effects that are not currently considered in the UAE EBD Model?	Addition of one pollutant: natural gas stoves The indoor air module as published in 2012 estimated the number of episodes of illnesses attributable to benzene, formaldehyde, radon, particulate matter ($PM_{2.5}$ and PM_{10}), mold, ETS, and incense. The results of this literature review support the addition of natural gas stoves as a contaminant.
Research Question 2: What epidemiological research on the relationship between exposure to indoor air	Addition of some pollutant-health effect relationships The literature review revealed a positive association between lower respiratory tract infections in infants and exposure to formaldehyde (Roda et al., 2011).

contaminants and health endpoints can be added to or modify the UAE EBD Model indoor air module?	The literature review revealed a meta-analysis that found a positive association between natural gas stoves and childhood asthma (Lin, Brunekreef, and Gehring, 2013)
	Use of more recently published epidemiological studies for some pollutant-health effect relationships Estimates from more recently published epidemiological studies can replace the relative risk estimates for the relationships between mold and adult asthma, mold and childhood asthma, and radon and lung cancer. In all cases where estimates from a newer study could replace estimates used in the original model, there was robust reasoning to replace the old study, such as a meta-analysis including more studies in its review, a case-control study containing more subjects, or more geographies represented in the study.
Research Question 3: What, if any, literature is available on measurements of exposure to indoor air contaminants that could be more accurate than the exposure information used in the UAE EBD Model?	Estimates of exposure to certain pollutants based on more recent publications Estimates of exposure to benzene indoors are based on literature published in developed nations up to the year 2020. Estimates of ETS are based on a UAE study published in 2018 (Al-Houqani et al., 2018).

Abbreviations: ETS, environmental tobacco smoke; UAE EBD, United Arab Emirates Environmental Burden of Disease Model.

B. Baseline Parameters and Health-Based Indicators and Targets for Indoor Air Quality

1. Introduction

The purpose of this part is to provide background on the environmental burden of disease related to indoor air pollutants.

2. Approach

The environmental burden of disease refers to the excess number of illnesses and deaths attributable to exposure to indoor air pollutants. In previous research, Drs. MacDonald Gibson, Thomsen, and others estimated that approximately 5% of deaths from cardiovascular diseases and 32% of lung cancer deaths in Abu Dhabi Emirate in the year 2008 were attributable to indoor air pollution. In addition, they estimated that some 22,000 visits to healthcare facilities were attributable to indoor air pollution in Abu Dhabi Emirate in 2008 (MacDonald Gibson, Thomsen, et al., 2013). Since that estimate, major environmental and policy changes have potentially affected IAQ in Abu Dhabi.

Furthermore, scientific research has continued into the health effects of indoor air contaminants of emerging concern. New estimates of diseases and mortalities attributable to indoor air pollution in Abu Dhabi Emirate will be estimated by updating the burden of disease model to reflect recent scientific literature and updated mortality and morbidity information.

Before updating burden of disease estimates, baseline parameters of the prior model must be established and updated. This part of the report therefore summarizes the baseline parameters used to estimate the burden of disease from indoor air pollutants and includes draft targets necessary to reduce the burden of disease from the selected indoor air pollutants. These baseline parameters include the total number of health care visits and mortalities in the Abu Dhabi population that may be influenced by the eight priority indoor air pollutants ($PM_{2.5}$, PM_{10}, radon, formaldehyde, benzene, ETS, mold, and incense combustion products), their concentration or exposure estimates in Abu Dhabi, and prior scientific information on the relationship between exposure to these contaminants and the increased risk of adverse health effects.

3. Findings

Table 16 includes a summary of health effects demonstrated to have an association with the eight indoor air pollutants, pollutant sources, exposure estimates, burden of disease estimates, and potential indoor air pollutant targets. MacDonald Gibson et al. (2013) included the eight priority indoor air pollutants in the original burden of disease model because they were identified as having a high presence in indoor residential air from a variety of sources and as having adverse human health impacts. This table includes only those health effects that had a demonstrated relationship between exposure to the selected contaminants and an increased risk of a specific adverse health endpoint. For example, benzene is a known human carcinogen, but Macdonald Gibson et al. (2013) were only able to model the health effect of asthma attributable to benzene.

Other health effects associated with exposure to the selected contaminants are the subject of a separate literature review that assesses the scientific evidence for the link between IAQ and health. The ICD-9 and ICD-10 codes (from the International Classification of Disease) used to collect information on health effects are included. Most importantly, the table includes estimates of healthcare facility visits and mortalities attributable to the eight indoor air pollutants as estimated by MacDonald Gibson et al. (2013). The number of healthcare visits and mortalities attributable to these health effects can be considered health-based indicators.

Exposure estimates are baseline values for Abu Dhabi residents' exposure to selected pollutants as published in MacDonald Gibson, Thomsen, et al. (2013). Exposure estimates are expressed as concentrations or as percentages of the population exposed to a contaminant. In the original model, concentrations from Abu Dhabi were available for $PM_{2.5}$, PM_{10}, formaldehyde, and radon, whereas international literature searches revealed concentrations for benzene. Estimates of exposure to mold were available from the United Arab Emirates Health and Lifestyle Survey (UAE University, 2002), and estimates of incense use frequency and ETS presence were collected in a health and lifestyle survey conducted by Yeatts et al. (2012).

The baseline burden of disease estimates include the estimates of excess healthcare facility visits and deaths per year in Abu Dhabi Emirate due to the modelled indoor air pollutants and their attributable fractions. The attributable fraction for each pollutant is the measure of the reduction in the specific health endpoint that would be possible if the risk factor were eliminated. For example, for $PM_{2.5}$, the attributable fraction is the proportion of healthcare visits due to childhood asthma in Abu Dhabi Emirate that could be prevented if indoor residential $PM_{2.5}$ were eliminated. The data indicate that 8.3% of healthcare facility visits for asthma in young children could be prevented if indoor residential $PM_{2.5}$ were eliminated. Thus, elimination of $PM_{2.5}$ would prevent 384 healthcare facility visits for asthma in young children (2–6 years).

Table 16: Summary of health effects of selected pollutants, estimated number of annual healthcare facility visits, and annual deaths due to indoor air pollutants, and potential indoor air targets (provided by Indiana University and RTI consultancy)

Indoor Air Pollutant	Associated Health Effect(s)	Pollutant Sources	Exposure Estimates			Burden of Disease Estimates		Potential Indoor Air Pollutant Targets
			Mean	**Median**	**99th Percentile**	**Healthcare Facility Visits***	**Deaths†**	
Particulate Matter and Chemicals								
$PM_{2.5}$	Asthma (ICD-9 493; ICD-10 J45)	Combustion processes (including smoking, cooking, and the burning of candles and incense); house dust; pets; infiltration from outdoors	30.6 μg/m^3	20.4 μg/m^3	163.7 μg/m^3	8.3% (384), children 2-6 years		10 μg/m^3 annual mean[a] 25 μg/m^3 24-hour mean[a] 65 μg/m 24-hour mean[b,c]
PM_{10}	Asthma (ICD-9 493; ICD-10 J45)	Combustion processes (including smoking, cooking, and the burning of candles and incense); house dust; pets; infiltration from outdoors	92.5 μg/m^3	50.5 μg/m^3	650.8 μg/m^3	47.7% (2202), children 2-6 years		20 μg/m^3 annual mean[a] 50 μg/m^3 24-hour mean[a]
Radon	Lung cancer (ICD-9 162; ICD-10 C33-34)	Construction materials; granite bedrock beneath buildings; cracks in building foundations	13.8 Bq/m^3	12.5 Bq/m^3	35.5 Bq/m^3	1.03% (0.85=~1)[b]	1.03% (0.26=<1)[d]	100 Bq/m^3 [e,f] 4 pCi/L (pCi/L)[g,h] or 148 Bq/m^3

Formaldehyde	Asthma (ICD-9 493; ICD-10 J45)	ETS; manufactured wood products; consumer products; furnishings	22.26 μg/m^3	7.5 μg/m^3	229.6 μg/m^3	0.00054% (25), children 2-6 years		100 μg/m^3 (30-minute average [i,j,k]) 55 μg/m^3 (acute) 9 μg/m^3 (8-hour) 9 μg/m^3 (chronic) [l,m]
Benzene	Asthma (ICD-9 493; ICD-10 J45)	ETS; outdoor air infiltration; consumer products (e.g., glues, paints, cleaning products); materials used in construction, remodeling, and decorating; intrusion of vapors from leaking underground storage tanks	9.5 μg/m^3	6.7 μg/m^3	45.7 μg/m^3	7.2% (334), children 2-6 years		17 μg/m^3 [n,o] 27 μg/m^3 (acute) 3 μg/m^3 (8-hour) 3 μg/m^3 (chronic)[l,p]

Indoor Air Pollutant	Associated Health Effect(s)	Pollutant Sources	Exposure Estimates	Healthcare Facility Visits*	Deaths †	Potential Indoor Air Pollutant Targets
Other Pollutants						
ETS	Lung cancer (ICD-9 162; ICD-10 C33-34); cardiovascular diseases (ICD-9 390-448; ICD-10 I00-79); leukemia (ICD-9 204-208.9; ICD-10 C91-95); respiratory infections (ICD-9 480-92; ICD-10 J09-18, J40-44); asthma (ICD-9 493; ICD-10 J45)	Tobacco products (including cigarettes, water pipe/shisha, and dokha/midwakh)	19% of the UAE population was estimated to be exposed to second-hand smoke at home (Yeatts et al., 2012)	Lung cancer: 4.5% (6) Cardiovascular: 4.5% (6123) of Leukemia: 19.6% (91) Lower respiratory infection: 9.8% (455), children <6 years Asthma: 8.4% (679), children < 18 years	Lung cancer: 5.5% (1) Cardiovascular: 10.8% (39)	0% - Exposure should be fully minimized in all indoor spaces.[q,r]

Mold	Asthma (ICD-9 493; ICD-10 J45)	Humid conditions and dampness; poorly maintained heating, ventilating, and air-conditioning equipment	16% of the UAE population were estimated to be exposed to mold, estimated from UAE Indoor Air, Health, and Lifestyle Survey (UAE University, 2002)	8% (857), adults 5.3% (431), children		0% - WHO guidelines for mold and moisture specify that persistent dampness and microbial growth on interior surfaces and in buildings should be avoided or minimized [s] California has no permissible exposure limit for mold, though the state aimed to establish one in 2005.[t] 30-60% humidity [u] 30-80% humidity [t]
Incense combustion products	Respiratory tract cancer (ICD-9 162; ICD-10 C33-34)	Oud; bakhour; frankincense and other resins	43.5% of the population uses incense daily. 42.9% of the population uses incense intermittently. 13.6% of the population never uses incense (Yeatts et al., 2012).[v]	30.3% (40)	30.3% (12)	No WHO guidelines establish recommended limits for exposure to incense burning of any kind. CA Air Resources Board encourages avoiding or reducing candle and incense burning.[w] Bakhoor and oud incense have been found to emit PM < 10 microns, CO, NO_x, and formaldehyde.[x]

Abbreviations: EPA, Environmental Protection Agency; ETS, environmental tobacco smoke; REL, reference exposure limit; WHO, World Health Organization
* Percent of healthcare facility visits for disease that are attributable to pollutant

† Percent of mortalities related to disease that are attributable to pollutant
a (WHO, 2006)
b (California Air Resources Board , 2005)
c 65 μg/m^3 guideline is based on a 24-hour measurement period. The California Air Resources Board recommended maximum indoor level is based on the U.S. EPA's National Ambient Air Quality Standard (California Air Resources Board , 2005).
d For radon, estimates of excess healthcare facility visits and deaths per year are for Abu Dhabi City specifically, not Abu Dhabi Emirate.
e (Zeeb, 2009)
f The WHO Handbook on Indoor Radon: A Public Health Perspective, published in 2009, notes that if the reference level of 100 Bq/m^3 cannot be implemented under prevailing country-specific conditions, the reference level for radon should not exceed 300 Bq/m^3. The handbook does not specify a sampling time-period in relation to the reference level (Zeeb, 2009).
g 4 pCi/L is the U.S. EPA's action level for radon. The EPA also recommends that building owners consider fixing radon problems if the concentration inside a building is above 2 pCi/L (USEPA, 2019). California does not have a higher action level than the U.S. EPA.
h (Jeong, n.d.) The Indoor Air Quality Control Act of Korea has a recommended guideline, not mandatory standard, for radon of 4 pCi/L.
i (WHO, 2010)
j The WHO recommended guideline for formaldehyde prevents sensory irritation. The guideline is also protective of lung function effects as well as nasopharyngeal cancer and myeloid leukemia (WHO, 2010).
k (Jeong, n.d.) The Indoor Air Quality Control Act of Korea has a mandatory standard for formaldehyde.
l (California Office of Environmental Health Hazard Assessment (OEHHA), 2019). RELs are used by California EPA agencies as indicators of potential adverse health impacts other than cancer.
m Acute, 8-hour, and chronic reference inhalation exposure levels are established by the California Office of Environmental Health Hazard Assessment (OEHHA). Acute RELs are based on an average exposure time of 1 hour. The acute REL for formaldehyde is based on sensory irritation to eyes, whereas the 8-hour and chronic REL is based on respiratory system effects.
n (WHO,2010)
o The concentrations of airborne benzene associated with an excess lifetime risk of leukemia of 1/10,000, 1/100,000 and 1/1,000,000 are 17, 1.7, and 0.17 μg/m^3, respectively (WHO, 2010). WHO guidelines state that no safe level of exposure to benzene can be recommended. The WHO has not recommended a reference level for benzene (WHO, 2010).
p The acute inhalation REL is based on development, immune system, and hematological system effects. The 8-hour and chronic RELs are based on hematological system effects (OEHHA, 2019).
q (WHO, 2003)
r Article 8 of the WHO Framework Convention on Tobacco Control dictates protection from exposure to tobacco smoke in indoor workplaces, public transport, indoor public places, and other public places as appropriate (WHO, 2003). According to the guidelines for implementation of Article 8, there is no safe level of exposure to tobacco smoke, and effective implementation of the Article requires the total elimination of smoking and tobacco smoke in a particular space or environment in order to create a 100% smoke-free environment (WHO, 2007).
s (WHO , 2009)
t The California 2001 Toxic Mold Protection Act directed the California Department of Public Health (CDPH) to determine the feasibility of establishing health-based permissible exposure limits (PELS) for indoor mold; however, the CDPH found that available evidence did not support the establishment of PELs for indoor molds, a finding that the CDPH still holds (California Department of a Public Health, 2020).
u (American Society of Heating, Refrigerating, and Air-Conditioning Engineers, Inc. (ASHRAE), 2004)
v Estimates assume all UAE residents, expatriates, and citizens use incense at the same frequency (MacDonald Gibson, Thomsen, et al., 2013)
w (California Air Resources Board , 2020)
x (Cohen, Sexton, & Yeatts, 2012)

Chapter 5: Discussion and Conclusion: Burden of Disease from Indoor Air Pollution in Abu Dhabi Emirate

1. Introduction

This chapter is part of an assessment of indoor air quality (IAQ) governance, policies, and regulations in Abu Dhabi. This project, supported by Abu Dhabi's Public Health Center (ADPHC), aims to assess the current state of knowledge regarding IAQ and improve IAQ and health governance, regulations, and strategic and operational planning in Abu Dhabi Emirate. One of this project's objectives is to update a prior review and model based on the scientific evidence regarding the relationship between IAQ in Abu Dhabi Emirate and the health of Abu Dhabi residents. This prior research, published by MacDonald Gibson et al. in 2013, was commissioned by the Environment Agency–Abu Dhabi and World Health Organization (WHO) Regional Office for the Eastern Mediterranean as part of an environmental health strategic planning project intended to assess the burden of disease in the UAE attributable to environmental pollution. This research team developed a computer simulation model known as the *UAE EBD Model*, which combines UAE public health data with environmental pollution data to estimate the number of premature deaths and medical facility visits attributable to environmental pollution in the UAE. The model is divided into modules, each focused on one type of pollutant exposure pathway. One module focuses on IAQ. Based on updated data availability, the *UAE EBD Model* can be updated.

2. Methods for estimating the burden of disease from indoor air pollution

People spend the majority of their time indoors in residential dwellings (Klepeis et al., 2001). Therefore, this modeling effort focuses on the residential environment. The model does not account for temporal variation in exposure or risks due to cumulative or aggregate exposure to pollutants.

This analysis of the burden of disease from indoor air pollution uses the attributable fraction approach advocated by the WHO. This approach for assessing the environmental burden of disease associated with selected risks (Prüss-Üstun et al., 2003) is based on the following steps:

1. Exposure assessment (estimating exposure to the environmental risk within the Abu Dhabi Emirate population)
2. Determination of the exposure-response relationship (using estimates from epidemiological studies that evaluate the relationship between exposure to a specific level of pollutant and risk of developing a specific adverse health effect)
3. Estimation of mortality and morbidity (calculating estimates of total healthcare episodes and mortalities in Abu Dhabi Emirate that result from specific health conditions)
4. Calculation of the attributable fraction (calculating the proportion of disease attributable to a given pollutant)
5. Determination of disease burden attributable to the risk (calculated by multiplying the total disease burden for the attributable fraction)

2.1 Priority pollutants

Nine pollutants or sources of pollution were selected for inclusion in the indoor air module of the modified *UAE EBD Model*. The *UAE EBD Model* as published in 2012 evaluated only eight priority pollutants, but the results of a literature review conducted as part of this project highlighted the importance of including natural gas stoves as a priority pollutant. The nine priority pollutants are:

- Environmental tobacco smoke (ETS)
- Incense combustion products
- Coarse particulate matter (<10 microns, known as PM_{10})
- Fine particulate matter (< 1.5 microns, known as $PM_{2.5}$)
- Radon
- Benzene
- Formaldehyde

- Mold
- Emissions from natural gas cooking, a major component of which is nitrogen dioxide (NO_2)

2.2 Exposure assessments: "exposure-based" vs. "scenario-based" approaches

The approach used in the *UAE EBD Model* requires treating exposure to pollutants as either "exposure-based," for which measurements of pollutants are required, or "scenario-based," for which percentages of the population who are exposed or unexposed to a pollutant are required. Some epidemiologic studies report relative-risk values based on measured levels of pollutants in the environment, resulting in "exposure-based" approaches. Other epidemiological studies estimate the relative risk based only on a qualitative categorization of whether an individual was exposed to the pollutant or not, using exposure levels such as "exposed" and "unexposed," or "high," "medium," and "low." When sufficient data exist to estimate the relative risk for a specific concentration of a pollutant and the fraction of the population exposed to that concentration, an approach WHO calls "exposure-based" can be used to estimate the attributable fraction. Otherwise, a "scenario-based" approach—categorizing the population into exposed and unexposed groups—is used. The exposure-based approach was used to estimate risks attributable to particulate matter, benzene, formaldehyde, and radon. The scenario-based approach was used to estimate risks attributable to ETS, incense combustion, mold, and natural gas stoves.

2.3 Pollutants assessed by an exposure-based approach: particulate matter, radon, benzene, and formaldehyde

Measurements of pollutants taken in homes in the UAE were available for particulate matter and formaldehyde (Yeatts et al., 2012). Measurements were also available for residential exposure to radon in Abu Dhabi City as published in MacDonald Gibson et al. (2013). A literature review of the measurements of indoor levels of benzene was conducted; estimates were pooled to reveal an estimate of the concentrations in Abu Dhabi Emirate homes. Table 17 shows the source and mean measurements for benzene, particulate matter, radon, and formaldehyde in the *UAE EBD Model*.

Table 17: Exposure assessment measurements for particulate matter, radon, benzene and formaldehyde

Pollutant	Concentration Mean (SD)	UAE EBD Model Source
Benzene	8.31 μg/m^3 (8.52)	Pooled estimates from international literature
Formaldehyde	22.5 μg/m^3 (63.6)	Measurements taken in the UAE (Yeatts, et al., 2012)
$PM_{2.5}$	30.6 μg/m^3 (34.4)	Measurements taken in the UAE (Yeatts, et al., 2012)
PM_{10}	92.8 μg/m^3 (144.9)	Measurements taken in the UAE (Yeatts, et al., 2012)
Radon	14.4 Bq/m^3 (7.37)	Measurements available for Abu Dhabi City as published in MacDonald Gibson et al. (2013)

Abbreviation: SD, standard deviation.

2.4 Pollutants assessed by a scenario-based approach: ETS, mold, incense combustion products, and natural gas stoves

The epidemiologic studies selected for these analyses did not present the relative risk on a per-unit-concentration basis but rather estimated risk for the exposed group relative to an unexposed group. Thus, exposure to mold, ETS, incense combustion products, and natural gas stove emission was expressed as a dichotomous variable (e.g., exposed/unexposed, ever/never). Table 18 shows the source and mean percent exposed ETS, incense combustion products, mold, and natural gas stove emission in the *UAE EBD Model.*

Table 18: Exposure assessment measurements for environmental tobacco smoke, incense combustion, mold, and natural gas stoves

Pollutant	Percent Population Exposed	UAE EBD Model Source
Environmental tobacco smoke	Adult women, children: 30% Adult men: 9%	Survey in UAE (Al-Houqani et al., 2018)
Incense combustion products	Daily use: 43.5% Intermittent use: 42.9% Never: 13.6%	Percent household exposure estimated in UAE survey (Yeatts, et al., 2012)
Mold	16%	Percent household exposure estimated in UAE survey (UAE University, 2002)
Natural gas stoves	17%	Percent household exposure for homes using natural gas stoves connected to the main home estimated in UAE survey (Yeatts et al., 2012)

2.4 Determination of the exposure-response relationship

A thorough review of the epidemiologic literature was conducted to estimate relative risks associated with indoor air pollution exposures. The health endpoints selected for the UAE analysis are well recognized as significant contributors to the health burden in many countries. Table 19 shows the relative-risk values used for each pollutant and health endpoint following an exposure-based approach along with the literature source from which the estimate was derived. Table 20 shows the relative risk values used for each pollutant and health endpoint following a scenario-based modeling approach, along with the literature source.

Table 19: Epidemiology parameters used to estimate risks for $PM_{2.5}$, PM_{10}, Radon, Benzene, and Formaldehyde exposure (exposure based)

Pollutant	Reference	Population	Health Endpoint	RR[a]	95% CI	Unit Exposure to Which RR Applies (ΔC)
$PM_{2.5}$	McCormack et al. 2009	2-5 yrs old	Asthma	1.03	0.99, 1.07	**10 μg/m^3**
PM_{10}	McCormack et al. 2009	2-5 yrs old	Asthma	1.06	1.01, 1.12	**10 μg/m^3**
Radon	Zhang et al. 2011	Adult	Lung cancer	1.07	1.04, 1.10	**100 Bq/m^3**
Benzene	Rumchev et al. 2004	6 mos to 3 yrs old	Asthma	1.09[2]	1.06, 1.12	**10 μg/m^3**
Formaldehyde	Rumchev et al. 2002	6 mos to 3 yrs old	Asthma	1.003[b]	1.002, 1.004	**10 μg/m^3**
	Roda et al. 2002	Less than 1 year	Lower respiratory tract infection	1.125[b]	1.048, 1.198	10 μg/m^3

Abbreviations: CI, confidence interval; $PM_{2.5}$, particulate matter < 2.5 microns; PM_{10}, particulate matter <10 microns; RR, relative risk.

[a] Relative risks for different concentrations and confidence intervals were estimated using the reported relative risks (RR) as shown and the unit exposure information. For all pollutants except radon, a log-linear concentration-response function was used, and the conversion was as follows:

$RR = e^{\left(\frac{\ln(RR)C_i}{\Delta C}\right)}$. For radon, based on Zhang et al. 2011, a linear concentration-response function with a slope of 0.08/100 Bq/m^3 was used.

[b] These studies reported odds ratios rather than relative risks. Odds ratios were converted to relative risks. The values shown here are the odds ratios (which are very close to the calculated relative risks due to the relatively low prevalence rates and odds ratios for the health endpoints indicated).

Table 20: Epidemiologic parameters used to estimate risks of environmental tobacco smoke, mold, incense, and natural gas stoves (scenario based)

Pollutant	Reference	Population	Health Endpoint	RR	95% CI
Environmental tobacco smoke	Kasim et al. 2005	Adult	Leukemia	2.28	1.15, 4.53
	Boffetta 2002	Adult	Lung cancer	1.25	1.15, 1.37
	Cardenas et al. 1997	Adult females	Lung cancer mortality	1.2	0.8, 1.6
		Adult males	Lung cancer mortality	1.1	0.6, 1.8
	He and Whelton 1999	Adult	Cardiovascular disease	1.25	1.17, 1.32
	Hill et al. 2007	Adult females	Cardiovascular disease mortality	1.35	1.11, 1.64
		Adult males	Cardiovascular disease mortality	1.25	1.06, 1.47
	Vork, Broadwin, and Blaisdell 2007	<18 yrs old	Asthma	1.48	1.32, 1.65
	Li et al. 1999	<6 yrs old	Lower respiratory tract infections	1.57	1.28, 1.91
Mold	Norbäck et al., 2013	Adult	Asthma	1.30	1.00, 1.68
	Tischer, Chen, and Heinrich (2011)	6-12 yrs old	Asthma	1.323	1.235, 1.573
Incense combustion	Friborg et al. 2008	Adult	Respiratory tract cancer	1.80	1.20, 2.60)
Natural gas stoves	Lin, Brunekreef, and Gehring (2013)	Children (<18 yrs old)	Asthma	1.267	1.153, 1.393

Abbreviations: CI, confidence interval; RR, relative risk.

2.6 Baseline mortality and morbidity

The observed baseline number of mortalities and healthcare episodes in Abu Dhabi was estimated by using health data provided in 2020 from the Abu Dhabi Department of Health (DOH). The DOH provided the number of mortalities or healthcare episodes caused by the selected health effects for the year 2019. All mortality and healthcare episode data were stratified by age, gender, and nationality (i.e., citizen or expatriate). The Abu Dhabi DOH defines an episode as "an inpatient encounter or set of outpatient encounters for the same patient with the same principal diagnosis that begins with a consultation" (Abu Dhabi Department of Health, 2020). The prior version of this model, published in 2012, used the number of healthcare facility visits as the estimate for the observed number of cases of the relevant health outcome in the population. Table 21 shows the total reported healthcare facility visits or episodes for diseases influenced by indoor air pollutants in Abu Dhabi Emirate in 2008 (the data available for the original *UAE EBD Model*) and 2019 (used in the updated model). Table 22 shows the total reported deaths from diseases influenced by indoor air pollutants in Abu Dhabi Emirate in 2008 and 2019.

Table 21: Total reported healthcare episodes for diseases influenced by indoor air pollutants in Abu Dhabi Emirate in 2008 and 2019 (source: DOH)

Cause of episode	ICD-10 Code(s)	Number of healthcare facility visits (year 2008)	Number of healthcare episodes (year 2019)
Asthma (<18)	J45	10,774	147,092
Asthma (>18)	J45	6,734	133,678
Cardiovascular diseases (>18)	I00-I79	135,021	390,513
Leukemia (>18)	C91-95	464	1,270
Lower respiratory tract infections (<6)	J20-J22	4,656	127,318
Lung cancer (>18)	C33-34	133	769
Respiratory tract cancer (>18)[a]	C33-C34	133	769

[a]The Abu Dhabi baseline estimates for respiratory tract cancer healthcare episodes included ICD-10 codes C33-34 (bronchus and lung cancer). In the future, respiratory tract carcinoma should include all cancers of the respiratory tract, including those of the nose, trachea, pharynx, larynx, bronchi, and lungs.

Table 22: Total reported deaths from causes influenced by indoor air pollutants in Abu Dhabi Emirate in 2008 and 2019 (source: DOH)

Cause of death	ICD-10 Code(s)	Number of deaths 2008	Number of deaths 2019
Cardiovascular disease (>18)	I00-I79	769	354
Leukemia (>18)	C91-95	43	54
Lung cancer (>18)	C33-C34	40	88
Respiratory tract cancer (>18)[a]	C33-C34, C39*	40	94

[a]The Abu Dhabi baseline estimates for respiratory tract cancer mortality included ICD-10 codes C33-34 (bronchus and lung cancer) and C39, unspecified carcinoma of the respiratory tract. In the future, respiratory tract cancer should include all cancers of the respiratory tract, including those of the nose, trachea, pharynx, larynx, bronchi, and lungs.

2.7 Calculation of the fraction of cases attributable to indoor air pollution

The attributable fraction is a measure of the reduction in a particular health endpoint that would be possible if the risk factor (i.e., pollutant or activity) were eliminated. The *UAE EBD Model* calculates the attributable fraction.

2.8 Determination of disease burden attributable to the risk

Table 23 summarizes the complete results of the estimates of excess healthcare episodes per year in Abu Dhabi Emirate that are due to the nine priority indoor air pollutants. Table 24 summarizes the mortality estimates. The tables show both the number of cases and the fraction of total cases attributable to indoor air pollution exposure. Figure 5 compares the number of healthcare episodes attributable to indoor air pollutants based on 2019 healthcare data to the estimated number of healthcare facility visits attributable to indoor air pollutants based on 2008 healthcare data. Figure 6 shows the number of estimated attributable mortalities in 2008 and 2019.

Table 23: Estimated number of annual health episodes attributable to indoor air pollutants in Abu Dhabi Emirate in 2019 (summary provided by Indiana University team)

Pollutant	Health Endpoint	Attributable Fraction (95% CI) 2008	Attributable Fraction (95% CI) 2019	Attributable Healthcare Facility Visits Abu Dhabi Emirate (95% CI) 2008	Attributable Health Episodes Abu Dhabi Emirate (95% CI) 2019
Environmental tobacco smoke	Lung cancer	All 0.045 (0.028, 0.060)	Females: 0.070 (0.043, 0.095)	6 (4, 8)	30 (19, 42)
			Males: 0.022 (0.013,0.031)		
	Cardiovascular disease	All 0.045 (0.031, 0.059)	Females: 0.070 (0.049, 0.09)	6,120 (4,220, 7,970)	31,500 (21,800, 40,900)
			Males: 0.022 (0.015, 0.029)		
	Chronic lymphocytic leukemia	All 0.19 (0.028, 0.31)	Females: 0.267 (0.045, 0.419)	91 (13, 146)	201 (31, 331)
			Males: 0.102 (0.014, 0.178)		
	Lower respiratory tract infections in children	0.097 (0.051, 0.14)	0.145 (0.078, 0.205)	455 (236, 653)	24,000 (12,900, 34,000)
	Childhood asthma	0.096 (0, 0.28)	0.138 (0, 0.383)	679 (0, 2,295)	20,200 (0, 56,400)
Radon	Lung cancer	City of Abu Dhabi: 0.011 (0.006, 0.019)	0.011 (0.006, 0.019)	1 (0,2)	5 (3, 9)

Benzene	Childhood asthma	0.072 (0.050, 0.095)	0.063 (0.043, 0.083)	334 (231, 436)	6,150 (4,251, 8,036)
Formaldehyde	Childhood asthma	0.014 (0.0092, 0.018)	0.005 (0.004, 0.007)	25 (17, 33)	520 (351, 687)
	Lower respiratory tract infections	N/A	0.230 (0.228, 0.231)	N/A	5,280 (5,250, 5,310)
PM_{10}	Childhood asthma	0.47 (0.092, 0.78)	0.47 (0.092, 0.78)	2,153 (1,280, 10,800)	45,300 (8,950, 75,400)
$PM_{2.5}$	Childhood asthma	0.084 (0, 0.19)	0.084 (0, 0.19)	390 (0, 874)	8,200 (0, 18,400)
Mold	Adult asthma	0.078 (0.0019, 0.146)	0.046 (0, 0.093)	845 (21, 1,570)	6,100 (0, 12,400)
	Childhood asthma	0.053 (0.031, 0.074)	0.049 (0.024, 0.073)	430 (253, 601)	7,200 (3,550, 10,700)
Incense combustion products	Respiratory tract cancer	0.3027 (0.079, 0.435)	0.3027 (0.079, 0.435)	39 (9, 49)	225 (60, 332)
Natural gas cooking	Childhood asthma	N/A	0.043 (0.020, 0.066)	N/A	6,370 (2,890, 9,720)

Abbreviations: CI, confidence interval; N/A, not available.

Table 24: Estimated number of annual deaths attributable to indoor air pollutants in Abu Dhabi in 2019

Pollutant	Health Endpoint	Attributable Fraction (95% CI) 2008	Attributable Fraction (95% CI) 2019	Attributable Annual Deaths Abu Dhabi Emirate (95% CI) 2008	Attributable Annual Deaths Abu Dhabi Emirate (95% CI) 2019
Environmental tobacco smoke	Lung cancer	Females: 0.039 (0, 0.102)	Females: 0.083 (0, 0.25)	1 (0, 4)	2 (0, 6)
		Males: 0.028 (0, 0.102)	Males: 0.061 (0, 0.25)		
	Cardiovascular disease	Females: 0.062 (0.033, 0.09)	Females: 0.13 (0.046, 0.24)	38 (10, 65)	15 (6, 24)
		Males: 0.045 (0.006, 0.082)	Males: 0.098 (0.012, 0.22)		
Radon	Lung cancer	City of Abu Dhabi: 0.011 (0.006, 0.019)	0.011 (0.006, 0.019)	0 (0,0)	1 (0,1)
Incense combustion products	Respiratory tract cancer	0.3027 (0.079, 0.435)	0.3027 (0.079, 0.435)	12 (3, 17)	28 (7, 41)

Abbreviation: CI, confidence interval.

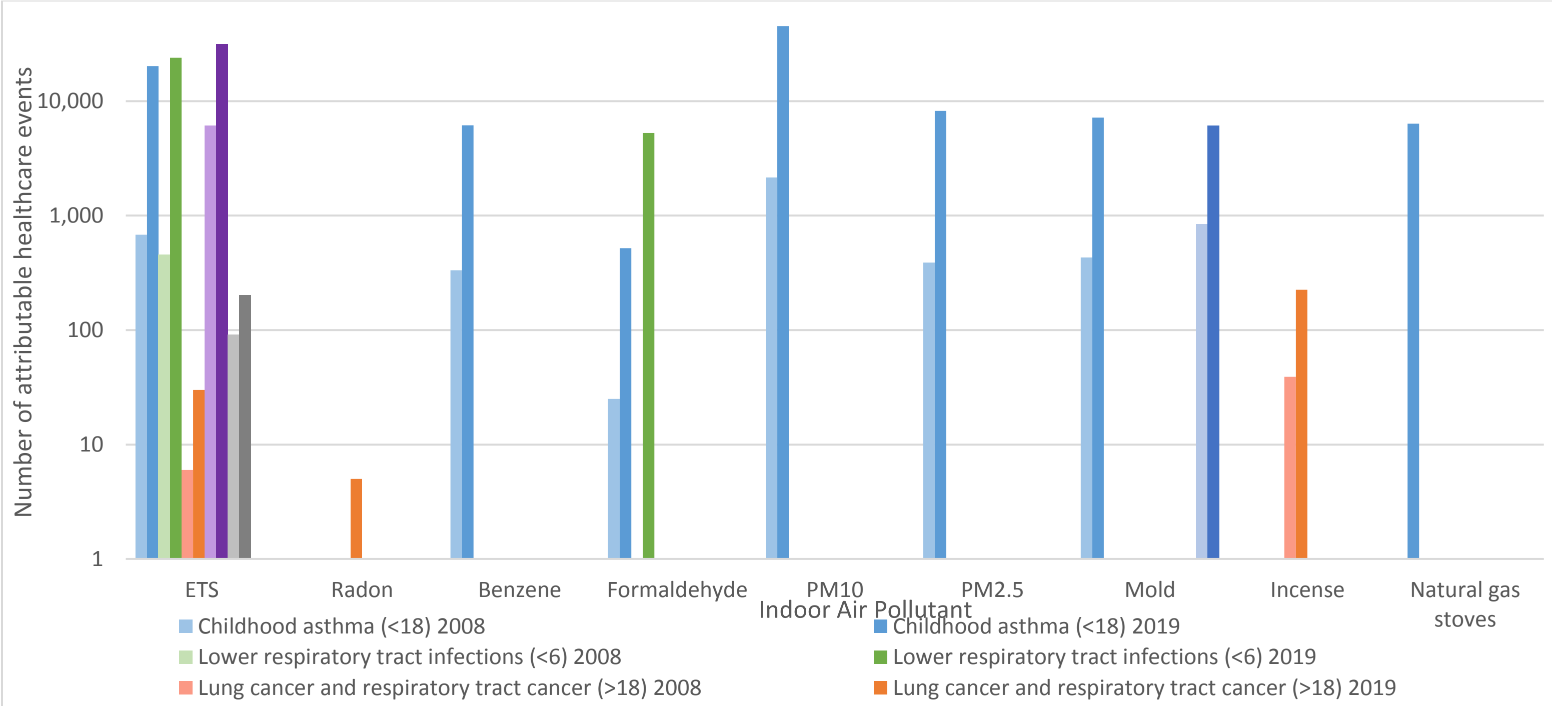


Figure 5: Estimated number of annual healthcare visits attributable to indoor air pollutants in Abu Dhabi Emirate in 2008 and in 2019. ETS, environmental tobacco smoke; PM10, particulate matter < 10 microns; PM2.5, particulate matter < 2.5 microns.

In Figure 5, the number of attributable healthcare events is shown in differently shaded pairs of the same color above the indoor air pollutant the health effects are attributed to. In 2008, healthcare events were measured as the total number of healthcare facility visits due to a selected health effect in Abu Dhabi Emirate. In 2019, healthcare events were measured as the total number of healthcare episodes that were due to a selected health effect in Abu Dhabi Emirate. For each pair, attributable healthcare facility visits for the year 2008 are shown to the left in a lighter shade, and attributable healthcare episodes for the year 2019 are shown to the right in a darker shade of the same color. Lastly, Figure 5 uses a logarithmic scale. Attributable healthcare facility visits for lung cancer attributable to radon in 2008 totaled one. Healthcare facility visits of lower respiratory tract infections attributable to formaldehyde and childhood asthma attributable to natural gas stoves were not estimated in 2008.

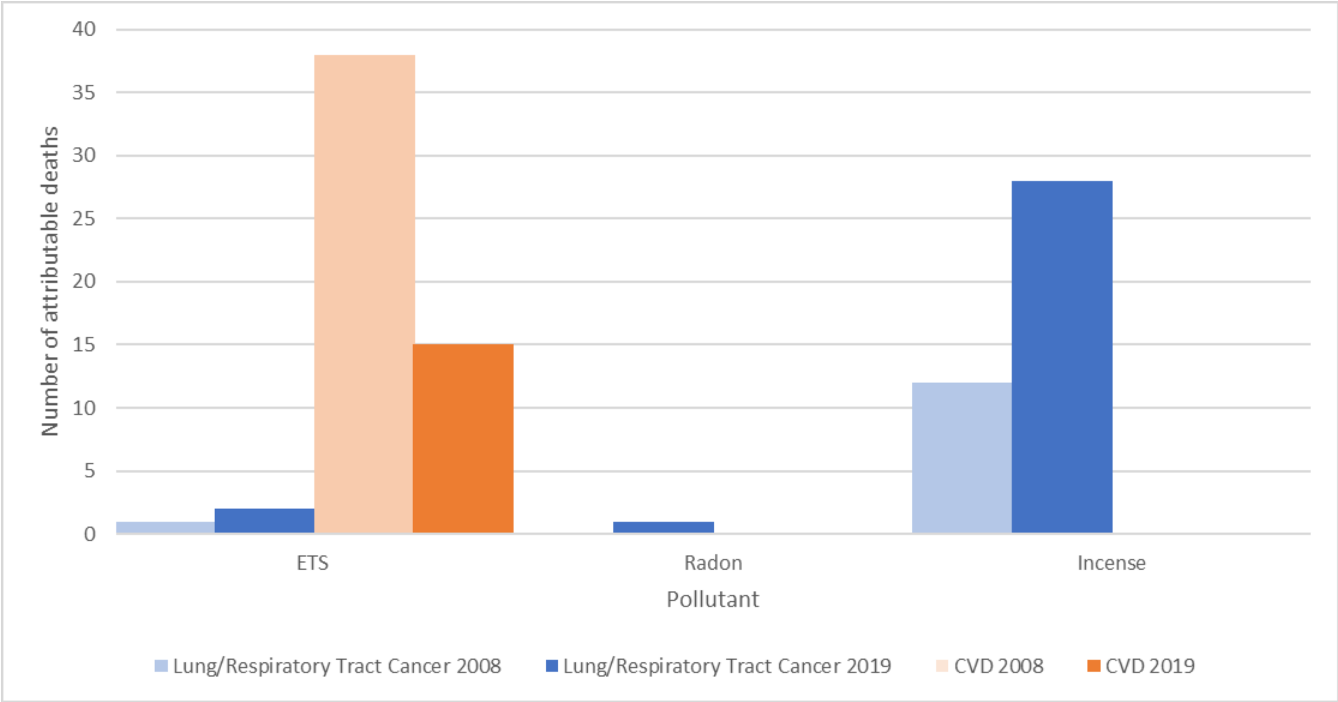


Figure 6: Estimated number of annual deaths attributable to indoor air pollutants in Abu Dhabi Emirate in 2008 and in 2019. ETS, environmental tobacco smoke.

In Figure 6, the number of attributable deaths is shown in differently shaded pairs of the same color above the indoor air pollutant the health effects are attributed to. For each pair, attributable deaths for the year 2008 are shown to the left in a lighter shade, and attributable healthcare episodes for the year 2019 are shown to the right in a darker shade of the same color.

3. Discussion and Conclusions

3.1 Overall burden of disease

The results of this analysis indicate that thousands of preventable healthcare episodes and tens of deaths can be attributed to indoor air pollution in Abu Dhabi Emirate for the year 2019. Table 23 shows the attributable fractions, or the fraction of all cases of a health effect that can be attributed to exposure to a pollutant, for the years 2008 and 2019, and the number of attributable healthcare events for nine indoor air pollutants for those years. This analysis shows that over 160,000 episodes of adverse health effects were attributable to nine indoor air pollutants in 2019 in Abu Dhabi Emirate. Table 24 shows the attributable fractions as well as the number of deaths that were attributable to exposure to indoor air pollution for the years 2008 and 2019. It shows that 46 deaths were attributable to indoor air pollution in 2019 in Abu Dhabi Emirate.

This analysis shows that ETS and particulate matter less than 10 microns in size are important indoor air pollutants in Abu Dhabi Emirate. Of the over 160,000 healthcare episodes attributable to indoor air pollutants in 2019, over half were related to ETS and PM_{10}. Over 75,000 healthcare episodes were attributable to ETS from all tobacco sources, such as cigarettes, shisha, and midwakh. The attributable burden of disease for ETS alone included over 31,000 episodes of cardiovascular disease, 24,000 episodes of lower respiratory tract infections in children, and 20,000 episodes of childhood asthma.

This finding indicates that ETS, which is also known as secondhand smoke, is a significant public health concern in Abu Dhabi Emirate. Over 45,000 healthcare episodes were attributable to indoor PM_{10}, which has many sources, including, but not limited to, generation through cooking, secondhand smoke, burning of incense or candles, and infiltration of ambient particulate matter. The remainder of the healthcare episodes were attributable to $PM_{2.5}$, benzene, formaldehyde, radon, mold, incense combustion, and natural gas cooking.

In Abu Dhabi Emirate in 2019, the leading health outcomes attributed to indoor air pollution were childhood asthma, cardiovascular disease, and lower respiratory tract infections in children. In total, over 90,000 episodes of childhood asthma were attributable to indoor air pollutants in Abu Dhabi Emirate in 2019. Of those, 45,000 were attributable to PM_{10}, around 20,000 were attributable to ETS, and the remainder were attributable to mold, natural gas smoke, benzene, and formaldehyde. Of the 160,000 healthcare episodes that were attributable to all indoor air pollutants considered, roughly 31,000 episodes of cardiovascular disease were attributable to ETS. Finally, over 29,000 episodes of lower respiratory tract infections were attributable to indoor air pollutants in 2019; of these, around 24,000 episodes were attributable to ETS, and around 5,000 were attributable to formaldehyde.

This analysis also showed that 46 deaths in 2019 were attributable to indoor air pollutant exposure. The majority of these deaths—28—were caused by respiratory tract cancer attributable to incense combustion. Another two deaths from lung cancer and 15 deaths from cardiovascular diseases were attributable to ETS exposure. Finally, one death from lung cancer was attributable to radon exposure.

3.2 Limitations of the model

The burden of disease estimates have important limitations. For example, this model does not account for synergistic effects of pollutants or for differing susceptibilities to health effects by age for some pollutants. Moreover, the predictions are highly sensitivity to relative risk estimates, and the model has the potential to underestimate.

First, the model does not account for synergistic effects of exposure to multiple indoor air pollutants. Although the model lists pollutants and health effects individually, contaminants may interact to cause new or exacerbated effects. The indoor environment is no different from the outdoor environment in that the air is a mixture and not simply composed of single pollutants. Multiple sources (e.g., stoves, furniture glues, candles, incense, and even the ventilation system) emit pollutants into the indoor environment.

This complexity of the air matrix creates challenges when assessing health effects and risks due to air pollution (whether indoor or outdoor) because current health thresholds are typically reported for individual pollutants.

For a few pollutants, scientific data have shown that concomitant exposure has the potential to cause a more-than-additive health response. For example, active smoking and radon exposure are known to interact synergistically with the potential to cause a multiplicative rather than additive risk for lung cancer (U.S. Environmental Protection Agency, 2010). Mixtures and potential interactions may increase the occurrence of adverse health effects from indoor exposures, as compared with estimates based on the presence of single contaminants. Studying the effects of pollutant mixtures on health is at the frontier of research, and not enough information is yet available to assess these mixture effects on the environmental burden of disease in Abu Dhabi Emirate.

A further important complication of assessing the health effects of indoor air pollutants is that children, the elderly, and people in poor health face a greater risk. This analysis accounts for differences between adult and child susceptibilities for some, but not all, health outcomes. Data limitations prevented the examination of special risks to elderly members of the population. The relative vulnerability of sensitive subgroups such as children and the elderly to environmental pollution in Abu Dhabi Emirate is an important topic for future research. Children under school age typically spend more time at home than do school-age children. Additionally, children of all ages tend to be more active than adults, resulting in an increased breathing rate and a potentially higher dose of pollutants on a per-body-weight basis. The elderly and people in poor health are also at increased risk because they spend large amounts of time in the home and have compromised health defense systems. The existing health conditions of those who are already in poor health may be exacerbated by peak, prolonged, and repeated exposures to indoor air pollutants.

A source of uncertainty in this analysis is the estimates of relative risks from exposure to indoor air pollutants. For these relative-risk estimates, the team relied on the most current global epidemiologic studies of the relationship between pollutant exposures and health effects. However, as illustrated in the sensitivity analysis published in MacDonald Gibson et al. (2013), the results of the predictions are highly sensitive to the assumed relative risk.

Finally, the estimates for the disease burden caused by indoor air pollutants are more than likely understated. In this study, only health effects from selected indoor air pollutants that were consistently indicated in the literature to have positive associations with adverse health impacts were evaluated. Evidence was inconclusive evidence for a positive association between other contaminants not considered in this analysis and adverse health effects. Evidence was also inconclusive regarding the positive association between health effects and some pollutants considered in this analysis. It is likely that morbidity and mortality numbers would be larger if additional indoor pollutants were assessed.

3.3 Changes in the burden of disease from 2008 to 2019

For all health effects that were influenced by indoor air pollutants, the total reported number of healthcare episodes in Abu Dhabi Emirate increased from around 12,000 in 2008 to over 160,000 in 2019. For many pollutants, the number of attributable healthcare episodes in 2019 was over 10 times the number of healthcare facility visits in 2008. Such a large increase warrants consideration.

Various factors could potentially be related to this large increase in estimated burden of disease from 2008 to 2019. First, the analysis shows that the large increase in the overall background number of healthcare episodes in Abu Dhabi Emirate is responsible for the increase in the burden of disease estimates. The inclusion of attributable fractions in Tables 23 and 24 shows that increases in attributable morbidity and mortality were largely due to overall increases in the overall number of healthcare episodes in Abu Dhabi Emirate, as the attributable fractions remained the same or similar. The addition of natural gas to the model and fewer respiratory tract infections attributable to formaldehyde accounted for only a small fraction of the overall increase in burden of disease.

It is unclear what factors caused the overall background number of healthcare episodes to increase so drastically from 2008 to 2019, but some potential causes include changes in data collection or reporting from 2008 to 2019 or a true increase in disease incidence from 2008 to 2019.

3.3.1 Changes in data collection

The first potential explanation for the discrepancy is the possibility that changes in data collection and reporting were responsible for an undercount in 2008 or an overestimation in 2019. Table 21 shows the number of healthcare facility visits that were provided in 2008 and the number of healthcare episodes that were provided by the Abu Dhabi DOH for the year 2019. The use of healthcare episodes should distinguish whether individuals made more than one visit. Potential changes in the methods of collection or reporting could have resulted in a large undercount in 2008 or overestimation in 2019.

Evaluations of the background health episode information for Abu Dhabi Emirate, made publicly available by the Abu Dhabi DOH Data Dashboard, support the accuracy of the 2019 data used in this analysis. The Abu Dhabi DOH Data Dashboard (Abu Dhabi Department of Health, 2020) states that in 2019, 4.95% of a total of 15.5 million healthcare episodes were due to respiratory diseases, and another 14.5% were due to respiratory infections. These percentages seem to align with the background healthcare episode data presented in Table 21.

A review of this health data dashboard for each year dating back to 2011 supports the notion that healthcare facility visits were underreported in 2008. For example, in 2011, the oldest year for which data are available in the dashboard, roughly 650,000 episodes (or 5% of a total 12.6 million healthcare episodes) were due to respiratory diseases, including, but not limited, to asthma. By comparison, only 17,000 healthcare facility visits due to asthma for all ages were reported for 2008.

3.3.2 Changes in population

The population of Abu Dhabi Emirate also increased from 1,492,300 at the end of 2007 to 2,986,000 in 2019, a near doubling of the population. However, the increase in population alone does not account for the near 10-fold increase in the number of background healthcare episodes.

3.3.3 Changes in incidence of diseases

A final potential explanation for the increase in total background healthcare episodes from 2008 to 2019 includes a true increase in the incidence of these diseases; however, there is not strong evidence that this is the case. Instead, estimates of asthma prevalence indicate that a change in disease incidence was unlikely responsible for the increase in the total background healthcare episodes from 2008 to 2019. Al-Maskari et al. (2000) reported that the incidence of doctor-diagnosed asthma was 13% in UAE school-aged children, and Alsowaidi, Abdulle, and Bersen (2010) reported a 12% incidence of asthma across the population of Al Ain. This reported prevalence of asthma supports the possibility that underreporting occurred in 2008, as the roughly 17,000 facility visits for asthma in Abu Dhabi Emirate out of a total population of 1,492,300 would equate to an incidence of only 1% for that year.

For 2019, the prevalence of asthma in the entire population would have been 9%, assuming all individuals with asthma went to a healthcare provider. This prevalence is much closer to the reported prevalence of asthma in the population according to Al-Maskari et al. (2000) and Alsowaidi, Abdulle, and Bersen (2010). If the true prevalence of asthma in Abu Dhabi Emirate is around 12-13%, it seems more likely that 9% of the population would be seeking medical attention for asthma, as seen in the 2019 health data, than 1% of the population, as the 2008 health data would suggest.

It therefore seems unlikely that a change in the incidence of asthma and other diseases included in this analysis is responsible for the differences in the total number of healthcare episodes. Instead, it appears that changes in data collection and reporting were responsible for an undercount of background healthcare information in 2008. Largely, the indoor air pollutants of major concern have remained the same.

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List of Appendices

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